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ERRATA.

Vol. LXIV.

Paper No. 1106.

The following corrections are published at the request of the author. They correct errors which were not made by the printer or the proof-reader.—EDITOR.

Page 114, foot-note: For "Heft 1" read "(Heft 1), 8."
Page 120, foot-note: For "125" read "1251."
Page 124, foot-note: For "Report for 1905" read "Report for 1905, 165."
Page 131, first foot-note: For "850, Zsigmondy" read "85."
Page 131, second foot-note: Strike out "1-77, 121 (1862)."
Page 134, foot-note: For "*loc. cit.*" read "46, 481."
Page 135, 8th line from bottom: The foot-note referring to Dunbar and Kryck should be: "Piefke—*Schilling's Jour. für Gas. und Wasser.*, 34, 85."
Page 135, 3d line from bottom: The foot note referring to Piefke should be: "See p. 155."
Page 136, Table 7: Strike out the figures in the last column and substitute:

"4.42, 5.00, 5.75, 9.73, and 10.57."

Page 136, foot-note: For "34" read "45."
Page 138, 9th line: Strike out "by Prinz's formula."
Page 138, 13th line:

For $K = \frac{1}{t} \times \frac{A}{A - x}$" read "$K = \frac{1}{t} \times 1_n \frac{A}{A - x}$."

Page 138, 15th line: For "waters showing high values of K are most readily purified" read "waters that are most readily purified show high values of K."

Page 138, first foot-note: For "35" read "45."
Page 138, seventh foot-note: For "*Gesundheits Ingenieur*, 1904," read "*Gesundheit*, 1904, 621; *Enteisenung von Grundwasser*."
Page 138, eighth foot-note: For "*loc. cit.*" read "*Jour. für Gas. und Wasser.*, 46, 486."
Page 138, ninth foot-note: Strike out "Report, Mass. State Board of Health, 1891; also."
Page 139, heading of Table 9: Add "(UNIT OF TIME = 100 HOURS)."
Page 139, Table 9: The figures in the last column should all be moved down one line, leaving the upper lines of each part of the column blank.

Page 146, second foot-note: For "*Loc. cit.*" read "See p. 156."
Page 149, first foot-note: For "108" read "121."
Page 150, foot-note: For "*loc. cit.*" read "30, 108."
Page 152, second foot-note: For "No. 1" read "(No. 1), 8."
Page 152, third foot-note: For "*Gesundheits Ingenieur*, 1904," read "*Gesundheit*, 1904, 625, *loc. cit.*"

Page 152, sixth foot-note: For "35, 517" read "34, 215, also 40, 378."
Page 152, seventh foot-note: For "35" read "85."
Page 155, second foot-note: For "40, 548" read "41, 528, 544."
Page 156, first foot-note: For "1907, p. 355" read "(1907), 31, 355."
Page 156, third foot-note: For "1908" read "(1908), 185 and 287."
Page 160, foot-note; Insert "Pippig," before "*Schilling's*," and for "40 (1896)" read "39, 650 (1896)."
Page 162, foot-note: Insert "Schertel," before "*Schilling's*," and add "49, 1022 (1906)."
Page 164, first foot-note: For "49, 714 (1906)" read "48, 614 (1905)."
Page 164, second foot-note: For "*Gesundheits Ingenieur*, 31, 364 (1906)" read "*Deutsche Bauzeitung* (1896), p. 445."
Page 168, second foot-note: Add the page number, "552."
Page 169, first foot-note: For "Report, Mass. State Board of Health, 1899" read "*Loc. cit.*"
Page 169, second foot-note: For "1908" read "(1908) 16, 241."
Page 172, first foot-note: For "186" read "193."
Page 174, third line from bottom: For "*ananganifera*" read "*manganifera.*"
Page 174, first foot-note: For "Aug. 17th, 1907" read "50, 767."

Paper No. 1107.

Page 226, Fig. 14: For "$\frac{h}{\sqrt{m}}$" read "$\frac{h}{\gamma\, m}$."

Page 227, line 3 from bottom: For "$p = d + \beta x$" read "$p = \alpha + \beta x$."

Page 227, last line: For "$q = \eta + \theta x + k x^2$" read "$q = \eta + \theta x + \kappa x^2$."

Page 228, line 1: For "k" read "κ."

Page 228, line 21: For "Pearsons" read "Pearson."

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TRANSACTIONS

Paper No. 1105

WATER-WORKS VALUATION AND FAIR RATES, IN THE LIGHT OF THE MAINE SUPREME COURT DECISIONS IN THE WATERVILLE AND BRUNSWICK CASES.*

By Leonard Metcalf, M. Am. Soc. C. E.

With Discussion by Messrs. C. S. Burns, James Nisbet Hazlehurst, Allen Hazen, T. H. McKenzie, L. L. Tribus, Gardner S. Williams, and Leonard Metcalf.

Eleven years ago a timely paper by Wynkoop Kiersted, M. Am. Soc. C. E., upon the "Valuation of Water-Works Property,"† and the very interesting discussion which followed it, shed much light on this important question, which was the outgrowth of a well-defined movement toward municipal ownership of water-works.

Since that time many plants have been taken by the municipalities which they were serving, and some noteworthy legal battles have been fought under the leadership of lawyers of unusual ability, assisted by experts in this field of engineering. In the course of this litigation the courts have handed down some important decisions, from among which two opinions, covering the broad legal and economic principles

*Kennebec Water District *v.* City of Waterville and others, Savage, J., 97 Maine, 185, and Brunswick and Topsham Water District *v.* Maine Water Company, Savage, J., 99 Maine, 371–389.

*Presented at the meeting of December 2d, 1908.

†*Transactions*, Am. Soc. C. E., Vol. XXXVIII, pp. 115–214.

underlying the subject of water-works valuation and rating, stand out in bold relief. These two opinions, rendered by the Supreme Court of Maine to guide two Boards of Appraisers in their valuation of certain water-works properties, were veritable beacons in the uncertain sea of public service corporation valuation and rating, and, with their application in three recent Maine cases and certain rulings in one of these—the Portland valuation case (by the tribunal upon which sat Judge Savage, the writer of the Maine opinions referred to, and one of his then Associate Justices, Judge Powers)—furnish the text for this paper.

The Waterville Opinion.

The opinion of Judge Savage, of the Supreme Court of Maine, in "Kennebec Water District *vs.* City of Waterville and others, Kennebec opinion, December 27, 1902," delivered in accordance with an act of the Legislature in advance of the taking, by the Kennebec Water District,* of the plant of the Maine Water Company (supplying the City of Waterville and the Towns of Winslow, Fairfield, and Benton), laid down for the first time instructions to appraisers—upon the law of eminent domain as applied to such cases, upon the considerations which should govern them in their determination of the value of the water-works plant taken, upon damages, and upon evidence—instructions which may be said to have become classic, so often have they been quoted by counsel in water-works valuation cases, and so large a part have they played in the trial of such cases.

Ambiguity of Waterville Opinion on Interrelation of Value and Fair Rates.

Good and helpful as was the Waterville decision, however, it was so vague and ambiguous, in its discussion of the interrelation of value and fair rates, as to leave the student in an endless circle of reasoning and a labyrinth of doubt as to its meaning upon this point. It held that:

"The property to be taken, both plant and franchises, are to be appraised, having in view their value as property in itself and their value as a source of income. There are these elements of value, but only one value of one entire property is to be appraised in the end.

*See article of Harvey D. Eaton, Esq., of Waterville, *Journal*, New England Water-Works Assoc., Vol. XIX, pp. 147–162, June, 1905. "The Maine Water Districts and Appraisals."

These elements necessarily shade into each other." (97 Maine, 185, Par. 27.)

"In addition to structure value, the appraisers should allow just compensation for all the franchises, rights and privileges to be taken." (Par. 22.)

"In estimating even the structure value of the plant, allowance should be made for the fact, if proved, that the Company's water system is a going concern with a profitable business established, and with a present income assured and now being earned." (Par. 19.)

"The value of the franchise depends upon its net earning power, present and prospective, developed and capable of development, at reasonable rates; and the value to be assessed is the value to the seller and not to the buyer." (Par. 23.)

Note the last statement that "the value of the franchise depends upon its net earning power, * * * at reasonable rates * * *." As to the latter, Judge Savage says:

"The basis of all calculation as to the reasonableness of rates to be charged by a public service corporation is the fair value of the property used by it for the convenience of the public." (97 Maine, 185, Par. 3.)

"The * * * Water Company is a quasi-public, or public service corporation, and is entitled to charge reasonable rates for its services, and no more." (Par. 2.)

Thus Judge Savage appeared to hold that the franchise value depended upon the reasonableness of the rates, and that the reasonableness of the rates must depend (among other things) upon the franchise value. First, determine the fairness of the rates, and then the franchise value; but before one can determine the fairness of the rates, one must determine the franchise value (as the rates are to be based upon the entire value including franchise); and before one can determine the franchise value one must determine the equitableness of the rates. The very hypothesis begged the question. How could the mystic circle be broken?

In referring to this opinion as being, in the above-mentioned respect, "vague and ambiguous," the writer has used the words advisedly for the reason that Judge Savage did appear nevertheless to have in mind the fundamental gauge for the reasonableness of the rates, the basic principle outlined so beautifully in his opinion in the Brunswick case, as will be shown later in this paper. Thus, he says in the Waterville decision (97 Maine, 185):

"At the same time, the public have the right to demand that the rates shall be no higher than the services are worth to them, not in the aggregate, but as individuals." (Par. 4.)

"Summarized, these elemental principles are, the right of the company to derive a fair income based upon the fair value of the property at the time it is being used for the public, taking into account the cost of maintenance or depreciation, and current operating expenses, and the right of the public to have no more exacted than the services in themselves are worth." (Par. 5.)

Had Judge Savage but omitted the last seven words in his Paragraph 4 (the first just quoted), and thus made his gauge or standard the worth of the service to the public, or had he changed the last words in Paragraph 5 to read "than the services are worth to them, in the aggregate or as individuals," as he did in substance in his later opinion, all confusion would have been avoided.

Abstract of Waterville Opinion.

However, if the Waterville opinion was weak in this respect, it laid down specific rules for the appraisers' (and counsels' and experts') guidance upon the following points—rules which have been of great service in these cases—and thus propounded the law in advance of the establishment of the essential facts in the case to be adjudicated, a very difficult, exacting, and dangerous task:

The property of the Company includes the real estate or other property, the plant or physical system, all franchises, rights and privileges, exercised or capable of being exercised. (97 Maine, Par. 1, 27.)

The real estate must be appraised at its fair market value, not at forced sale, but at worth to seller under prudent and beneficial sale. (Par. 1, 7.)

Actual construction cost (with proper allowance for depreciation) and reproduction cost are competent but not conclusive or controlling evidence. (Par. 8.)

Structure value should include going concern with a profitable business established, and with a present income assured and now being earned, if proved. (Par. 19.) Good will should not be considered so far as the water system is practically exclusive. (Par. 20.)

In fixing structure value, including the element of going concern, consider also the present efficiency of the system, quality of the water and service, fitness of the plant and of the sources of water supply to meet reasonable requirements in present or future, necessary time to construct *de novo*, and the time and cost needed after construction to develop such new system to the level of the present one in respect to business

and income, and the added net income and profits which would accrue during this period of construction and development.* (Par. 11, 21.)

Franchise value depends upon its net earning power, under reasonable rates. The value to be assessed is the value to the seller, not the buyer, but always subject to the fairness of the rates. (Par 23.) So-called unlimited franchises are neither perpetual nor irrevocable (Par. 7), nevertheless the fact that the franchises are to be taken in no respect impairs their value. (Par. 26.) Past unfaithfulness, misbehavior or delinquencies of Company involving perhaps liability to forfeiture of the franchises are not a consideration. (Par. 13, 14.) In considering prospective development and use of the franchise, the further investment necessary and effect upon income and rates are pertinent matters. (Par. 24.)

The basis of all calculation as to the reasonableness of the rates is the fair value of the property used by the public service corporation for the convenience of the public, and the Company is entitled to charge reasonable rates for its service and no more. (Par. 3, 5, 2.) No more shall be exacted from the public than the services in themselves are worth, or are worth to the public as individuals. (Par. 4, 5.) The actual earnings of and rates charged by the Company are admissible evidence, but their weight is dependent upon the reasonableness of the rates, among other things. (Par. 10.) The early hazard and losses are also to be considered with reference to the past income, which might otherwise have been excessive. (Par. 6.) Even if excessive, no deduction is to be made for the rates collected in the past, but the fact is to be borne in mind in considering the present or future income. (Par. 15.)

"Capitalization of income, even at reasonable rates, cannot be adopted as a sufficient or satisfactory test of present value. But while not a test, present and probable future earnings at reasonable rates are properly to be considered in determining the present value of the system."

The Brunswick Opinion.

In 1905 the Brunswick and Topsham Water District took the works of the Maine Water Company, supplying the City of Brunswick (leaving to the Company that portion of its plant supplying the City of Bath), and, as in the Waterville case, under legislative authority, obtained from the Supreme Court of Maine, in advance of the trial of the case, an opinion covering the same general ground as the Waterville opinion—eminent domain, instruction to appraisers, franchise valuation, damages, evidence, and private and special laws.†

* The latter would seem to come rather under the head of franchise and future earnings than under structure value and going concern.

† Brunswick and Topsham Water District *v.* Maine Water Company, Savage, J., 99 Maine, 371–389.

Fortunately this duty again fell to Judge Savage, for it gave him the opportunity to clear up the ambiguity of his earlier decision and to carry forward his admirable work—for these two masterly decisions bid fair to play a most important part in the future, not only in water-works valuation, but also in "fair-rates" cases involving other public service corporations.

Abstract of Brunswick Opinion.

The legislature is not competent to prescribe rules for damage, but rules assented to by the inhabitants of the water district are made binding by their approval of the charter. (Maine, 99, p. 12.)

Actual construction cost bears upon reasonableness of rates and present value, but is not conclusive. If by rise of prices the present value is greater than the original cost, the owner is entitled to the appreciation; if less, he must suffer the loss. (Par. 4.)

Structure value must include consideration of the facts that the structure is in use, is a going concern, is lawfully in use—that is, that the structure is a going concern in use by virtue of a franchise. (Par. 2, 3.)

The reproduction cost is to be figured as of the date of taking at prices for materials and labor during a period long enough before that time for the construction and final completion of the works on the date of taking; and interest during the construction period is to be allowed upon the money invested as a part of the construction cost. (Par. 10.)

Reasonableness of the rates must be based upon the fair value of the property used by the company for the service of the public, including therein not only structure and going concern values, but also franchise value. (Par. 1.) The reasonableness of the rates relates to both the owner and the customer, but in case of conflict the rates must in any event be reasonable to the customer. (Par. 6.) The reasonableness of rates must be determined by the preponderance of evidence. (Par. 9.) The amount of money actually and wisely expended in producing the plant is a primary consideration. (Par. 5.) Profits which in the aggregate exceed a fair return on the property and franchise of the company do involve unreasonable rates. (Par. 8.)

Worth of the Service.—"A public service company cannot lawfully charge more than the services are reasonably worth to the public as individuals, even if charges so limited would fail to produce a fair return to the owner upon his property or investment." (Par. 7.)

"The worth of a water service in such connection is the worth to the customers as individuals, but as individuals making up a community of water takers." (Par. 14.)

"In estimating the value of a public service to the public or the customers, one of the elements necessary to be considered is the expense at which the public or customers, as a community, might serve themselves, were they free to do so, and were it not for the practically exclusive franchises of the supplying company. Water is to be regarded as a product, and the cost at which it can be produced or distributed is an important, though not the only, element of its worth." (Par. 13.)

Communities are entitled to the benefit of natural advantages, and the company is not entitled to charge enhanced rates based upon the cost of using the more expensive source. (Par. 15.)

Damages for severance are to be allowed. (Par. 11, 16.)

Eminent domain.—The award is to be made under the principles of eminent domain and upon such principles of eminent domain as were agreed to by the voting constituents of the water district by approving the charter.

General Considerations Affecting Water-Works Valuation and Fair Rates.

The following outline indicates in a general way the more important considerations bearing upon water-works valuation and rating and the scope of the inquiry which the expert will be likely to wish to make in order to form his judgment as to the value of any particular works or the fairness of the rates charged by them:

A.—Data Relating to Community.—

1.—Character of population, and industries and buildings.

2.—Population: Past, present, and probable future; United States, State, and Local Censuses.

3.—Assessed valuation: Past and present.

B.—History of Plant and Dates of Construction and Further Development.

C.—Legal Rights.—

1.—Form of incorporation: Charter.

2.—Franchise: Exclusive or not, perpetual or limited, terms of purchase or extension.

3.—Contracts for public and private water service: Terms, time, and prices.

4.—Tax exemption or otherwise. Tax rates. Amount of taxes.

5.—General laws affecting company: Local ordinances or orders.

D.—Physical Plant.—

1.—Source of supply: Character; artesian, ground, surface.

2.—Population on water-sheds, and sanitary conditions.

3.—Quality.

4.—Quantity; available drainage area, storage and pondage, variation in yield.

5.—Adequacy for present and probable future needs.

6.—Local rainfall and flow statistics.

7.—Number of taps, services, and consumers; number of meters.

8.—Water consumption and uses: Gallons, average per day, total, per capita, per service, or tap.

9.—Variation in and character of consumption.

10.—Reservoir system: Character, amount, location or distribution.

11.—Pipe distribution system: Character, kind, and extent.

12.—Efficiency: Age, deterioration, probable life, effects of electrolysis, etc.

13.—Available domestic supply, quantity and pressure.

14.—Available fire supply, number and character of streams.

15.—Adequacy of service as compared with present and probable future needs.

16.—Necessary re-enforcement.

17.—Possible competitive sources of supply, with data for comparative estimates of cost.

18.—Pumping plant and data relating to operation.

19.—Purification plant and data, sedimentation, filtration, softening, etc.

20.—Plans: General and detail; elevations, etc.

E.—Local Prices of Labor and Building Materials; Hours of Employment; Ordinances in Regard to Labor, etc.

F.—Rates.—

1.—Schedule of public, commercial, and domestic rates, past and present.

2.—Rates elsewhere in vicinity (probably not admissible as evidence, but of service to experts).

G.—Operating Statistics.—(Annual for period of years, or during whole life of plant, if possible.)

1.—Gross income.

a.—Classification of gross income: Public hydrants and other uses; private fire service; domestic and manufacturing; metered and fixture service; license or permit for tapping; profit on services; house plumbing, etc.

2.—Operating expenses.

a.—Administration salaries and wages; legal, engineering, general, and miscellaneous expense.

b.—Buildings and real estate: Rental, care and repairs.

c.—Pumping: Labor, fuel, oil and waste, sundries, repairs.

d.—Filtration: Labor, chemical coagulation supplies, sundries, repairs.

e.—Street mains and service pipe work: Labor, supplies, miscellaneous repairs.

f.—Meters: Labor, supplies, miscellaneous repairs.

g.—Insurance and taxes.

3.—Net income = gross income less operating expenses.

4.—Maintenance = depreciation plus renewals.

5.—Fixed charges: Interest on bonds and floating loans.

6.—Sinking fund requirements.

7.—Dividends on stock, and surplus.

8.—Unit figures: Gross and net income, per million gallons daily, per tap, per capita, per mile of pipe, to be derived from the above.

H.—Sinking Fund, Surplus, and Interest and Dividends Paid in Past, and Resulting Average Earnings upon Original Cost or Investment.

I.—Real Estate and Water Rights, etc.—

1.—Cost of.

2.—Market value of.

3.—Assessed value of.

J.—Structure Value.—

1.—Original cost of original plant and subsequent extensions and betterments:

a.—Date and amount of.

b.—Character of prices, as compared with normal prices of that time.

c.—Reasonableness of outlays and provisions for the future.

d.—Date and amount of extensions and betterments.

2.—Reproduction cost as of date of taking, buying materials sufficiently in advance to have plant ready for operation on date of taking.

3.—Depreciation: Annual and total to date.

4.—Cost of betterments or necessary improvement of service, completed as of date of taking.

a.—Anticipated increase in earnings from these betterments.

b.—Anticipated increase or decrease in operating expenses from these betterments.

c.—Depreciation and fixed charges upon these betterments.

d.—Difference, or net increment or charge.

5.—Competitive sources. Cost of and charges that would result.

K.—Lawful Rates and Value.—

1.—Reasonable ratio of profit to the owner or promoter in excess of the actual reasonable cost of the property. This must be limited by the consideration of the profit or excess over cost which the public would probably have been willing to allow the corporation at the time of its incorporation, as compensation for relieving the city of the necessity of undertaking the work itself, as it might have done at cost, but which it then elected to have done for it at cost plus profit. (The reasonable amount of this profit will be discussed hereafter.)

2.—Rate of interest to be allowed upon investment, or property, commensurate with property of equal security, safety, and risk.

3.—Annual allowance for depreciation.

4.—Market value of real estate and supplies on hand.

5.—Worth of service to consumer or lawful gross annual income for given investment. Reasonable annual operating cost including repairs; plus annual depreciation: plus interest upon the sum of the reproduction cost* and profit increment less total depreciation to date (if the

* The reasonableness of using a fair average reproduction cost instead of the reproduction cost upon the date of taking, or the original cost, is discussed later.

latter has been previously earned). This sum measures the lawful annual gross income, if the works are capable of earning it.

6.—Comparison of lawful with actual annual gross income.

7.—Value determined by reproduction cost plus profit increment less total depreciation to date (if previously earned), plus market value of real estate and supplies on hand, provided the actual annual gross income equals or exceeds the lawful annual gross income.

8.—If actual annual gross income is less than the above determined lawful annual gross income, value is determined by capitalizing, at the assumed fair rate of interest, the actual net income derived by deducting from the gross annual income the operating expenses and annual depreciation allowance; increasing this sum by the market value of the real estate, and decreasing it by the depreciation to date (if the latter has been earned previously in the rates).

9.—Calculate equivalent annual rate of return to the owner of this lawful income, upon the actual cost and upon the fair average reproduction cost of the works.

10.—Corrections to be applied on account of necessary betterment or improvement in efficiency of the plant, with due allowance for any possible increase as well as decrease in income, operating expenses, maintenance and fixed charges.

11.—Resulting value to owner, subject to limitation of reasonable rates and reasonably efficient service (including therein the necessary improvements or betterments).

L.—Results to City of Award of Assumed Value.—

1.—Assumed value or award.

2.—Annual combined cost of operation, depreciation and (or) sinking fund, and interest upon investment.

3.—Present annual income.

4.—Net result upon present conditions.

5.—Similar figures with allowance for increase or decrease in earnings, operating expenses, depreciation and fixed charges, due to betterments or necessary improvement of

efficiency or standard of service. It may be of interest, though not logically correct, to include in the total investment the actual cost to the city of acquiring the property, that is, the cost of court, legal, expert, and witness fees and expenses.

M.—Going Concern Element of Value.—(Note that this element of value is included in the above valuation, and is of significance or importance chiefly in cases involving valuation of plants taken after expiration of their franchises.)

Company's Plant.	*Newly Built Municipal Plant.*
First Year.—Net annual income at date of taking.	Probable gross income for year, less operating expenses, plus saving in state and county taxes.*
Loss in first year by operation of new plant by city.	
Second year.—Net annual income as of date of taking.	Probable gross income for year, less operating expenses, plus saving in state and county taxes.*
Loss in second year by operation of new plant by city.	

Similarly for third, fourth, etc., years, to time at which the city may be assumed to have developed the business to a point equal to the net annual income at date of taking.

The total sum of the present worths of these annual losses may be considered to be the "going concern value."

N.—The Subjoined Form for Collecting and Preserving Financial Data Relating to Water-Works.—This form (page 13), used by the writer for some years, may also be of service.

Some Comments Upon the Above Considerations Affecting Water-Works Valuation and Rates.

Legal Rights.

Inasmuch as the majority of Maine water-works franchises may be classed under the popular head of "perpetual franchises," and as

* Interest charges not included, as they are the same for both plants, if we assume both plants ready for operation as of date of taking. Annual depreciation assumed to be the same for both plants, hence ignored. The town taxes are not assumed to be saved by the town, as it must make good, by general taxation, any loss from reduction of taxes upon Company's plant or abolition thereof in case of taking of the plant by the city.

WATER-WORKS STATISTICS.

Information obtained ..... 19.....
" " by ..... Place .....

Year									
Population									
Gravity or Pumping									
Miles of Pipe, all kinds									
" " C.I. pipe only									
Pop. per mile of pipe									
Range of sizes									
% Wrought Iron									
Taps in Service-live									
Per 1000 population									
Per mile of pipe									
Persons per tap									
Meters									
% of taps metered									
Consump. Annual, mil. gals.									
Daily g. d.									
Per capita. g. d.									
Per mile of pipe, g. d.									
Per tap, g. d.									
Pressure (range) lbs.									
Hydrants, number									
Per 1000 population									
Per mile of Pipe									
Gross Income, Total									
Per capita									
Per mile of pipe									
Per tap									
Per m. g. consump.									
Gross Inc. excl. Hyds.									
Per capita									
Per mile of pipe									
Per tap									
Per mil. gals.									
Cost of Operation									
Per capita									
Per mile of pipe									
Per tap									
Per mil. gals.									
% of Gross Income									
Net Inc. excl. interest									
Per capita									
Per mile of pipe									
Per tap									
Per mil. gals.									
% of gross									
Hydrant Rental									
Per hydrant									
Per mile of pipe									
Taxes, Annual									
% of Gross Income									
Bonds									
Rate of Interest									
Capital Stock									
Floating Debt									

the illustrations given in this paper come under this class, the discussion has been limited to franchises of this class. The general principle of the worth of the service to the consumer is equally applicable and valuable, however, in its bearing upon fair rates, to limited term franchises.

Original Cost.

The Brunswick opinion gives new life and significance to the original cost, which, heretofore, has received comparatively little consideration, if any, in valuation proceedings in the United States, other than in its remote bearing upon the total depreciation of the plant to date. While it is recognized that in many, perhaps in most, cases it may not be possible to determine the actual first cost, it may, where available, have a very important bearing upon the case, particularly if the cost was a normal and reasonable one at the date of construction.

The reasonable annual return to be allowed the builder of the works upon their original cost (referred to later) is largely a matter of judgment, and will be influenced by many considerations. Roughly speaking, it may vary from 7 to 10% or even more, the smaller rate reflecting the larger works, the better topographical or physical conditions, the more promising field, the greater ease and lesser expense of making provision for the future, etc., the greater freedom from danger of competition, the smaller hazard, and the more stable character of the community; the larger rate reflecting the reverse.

Reproduction Cost.

This cost has always been recognized as pertinent and important, though not controlling, in valuation cases.

It has had its greatest influence in the case of works taken after expiration of franchise, when the reproduction cost, depreciation, and going concern value have been very important, if not controlling, elements of value.

Even so, under the Brunswick ruling, reproduction cost has a new force in its bearing upon the cost to the public of supplying itself—the worth of the service to the consumer—and hence upon the reasonableness of the rates. Upon the latter subject more will be said under the caption of the "Measure of Fair Rates."

Reproduction Cost.—Court Rulings upon Prices to be Assumed.—The method of figuring the reproduction cost of the plant, prescribed

by the courts in different States, varies considerably, so that the results obtained under one ruling may be quite different from those obtained under another, particularly in large plants involving a construction period of several years.

The Maine opinions clearly prescribe the assumption of prices prevailing at a time in advance of or prior to the date of taking, corresponding to the probable period of construction, upon the theory that the plant is to be built and delivered complete upon the actual date of taking.

In the Kansas City case,* and in a number of other cases, on the other hand, prices prevailing upon the date of the taking were taken, upon the theory that the valuation was made as of the date of taking and hence that the prices of that date should be assumed.

Thus, in the Portland (Maine) valuation suit, the several engineers assumed periods of construction from 2 to 3 years, and made allowance for the interest charges upon construction within this period, with a resulting agreed reproduction cost, including hydrants (owned by the city) and services (laid at the expense of the water takers), of $2 853 696, cast-iron pipe being figured at approximately $29 per net ton—all under the Maine ruling before referred to. Had the Kansas City ruling been used, the price of cast-iron pipe would have been approximately $25, with a reduction in the reproduction cost of about $80 000. While the deduction for depreciation would have offset this decrease in some measure, the net results would still have been much less.

This illustration leads to the natural suggestion that in equity, at least, a reproduction cost based upon normal or average prices for a period of years prior to date of taking would be a fairer criterion than one based upon the monthly or daily fluctuations of the material and labor market.†

Reproduction Cost.—Identical Structure vs. Structure of Equal Efficiency.—The courts are also divided upon the subject as to whether, in calculating the reproduction cost of a structure, the actual lines of the structure or, in other words, the identical structure under consideration should be adhered to, or, on the other hand, whether the cost may be measured by that of a structure of equal efficiency. The

* National Water-Works Company *vs.* Kansas City, 62 Federal Reporter, 853-869.

† See also pages 35, 36, 39 *et seq.*

Maine Courts have taken the former view, the Federal Court in the Kansas City suit, the latter. In a comparatively new or young plant the difference may be insignificant, in an old plant it is likely to be large. Something may be said in favor of both methods, though the latter, if reasonably applied, would appear to have greater merit from a business standpoint. The owner may claim that the plant, though obsolete or old-fashioned and not what he would build were he building anew on the date of taking, is still serving the public adequately; whereas the buyer of the plant would not be likely to value a multiplicity of parts, as, for instance, three or four supply mains, built in sequence and costing far more than one unit, at a materially higher figure than one equivalent unit, except perhaps in so far as duplication may give an added factor of safety in operation. Moreover, if, through the agency of the rates, the owner of the property has collected from the public a depreciation allowance sufficient to make good this loss in efficiency, it is but just to the public and not unfair to him to consider reproduction cost from the point of view of a structure of equal efficiency rather than of identical parts. Whatever the views of the expert, however, the laws of the community or the counsels' interpretation of them will hold.

Depreciation.

A water-works system has a limited life or period of usefulness. The structure suffers depreciation with the lapse of time. The various elements composing the physical plant have to be removed and replaced from time to time. Broadly speaking, this depreciation may be classified under physical and functional depreciation, and, in certain cases, perhaps, under a third class growing out of expediency or extraordinary external requirements. By physical depreciation is meant the actual wear and tear of operation upon the structure; by functional depreciation, the obsolescence of the structure or its inability, for one reason or another, effectively to meet throughout its life the full requirements of the service. Thus the structure may suffer total depreciation and be thrown out of service, not only because through wear and tear it has reached a condition where further expenditures for repairs or attempts to make it suitable for the required service would not be economical or expedient, but also because recent improvements, or new inventions, new developments and radical changes in service, or

the demands of one kind or another involving sweeping changes in the existing plant, make abandonment necessary.

The rates of depreciation of the different component parts of a water-works system vary greatly, both in the final limit of useful life and in the progress or rate of depreciation during that life. The depreciation may be at a uniform rate, or at a variable rate, or indeed at an irregular rate, depending upon various factors. Thus, in the case of a reservoir, the structure may suffer substantially no depreciation until the time when it has to be abandoned by the requirements of larger size, greater pressure, or other detail of service; when this time does come, if the reservoir is actually abandoned, it suffers total depreciation, or, if it continues to serve a partial need, partial depreciation. A pumping engine may suffer virtually no depreciation in the first year of its life, indeed it may run more smoothly than when new; thereafter, it may depreciate steadily, if slightly, until it is outgrown and another larger machine has to be added, when it suddenly suffers a very large depreciation; it may then be used as an auxiliary machine for a portion of the time for a further period of years, until even this limited use proves uneconomical, though the engine may be held for emergency use for some time until it is finally abandoned, and only junk value less cost of removal remains. Clearly such a life history may be a very erratic one.

Three general methods of calculating the total depreciation of a water-works plant, at any time in its life history, have been developed: First, the sinking-fund method; second, the constant-rate or straight-line method; and, third, what might be termed the individual analysis method, by consideration of the local conditions, more particularly with their reference to one another and their bearing upon the general efficiency of the plant.

Allen Hazen, M. Am. Soc. C. E. (and perhaps others) has suggested that in calculating the depreciation of cast-iron pipe, a consideration of the loss in carrying capacity would furnish an added criterion. It certainly does, although its direct application is impossible, for the reason that the pipe system is designed with some regard for this very factor—gradual loss in carrying capacity—hence, to charge a greater depreciation in the early life of the plant in addition to the burden of the greater pipe sizes used to meet this very contingency, would be to make a double charge against earnings. By

this criterion the loss in the early years of the life of the pipes would exceed that resulting from the application of the sinking-fund method. The true results may lie somewhere between the two, though if the assumed life of the structure in the sinking-fund method be moderate, any allowance on this score may be excessive.

In the opinion of the writer, all these methods are but aids to judgment, and must be applied with care and discretion, and with a clear conception of the extent of the modifying influences or considerations; no subject in the engineering field requires richer experience or riper judgment. Obviously, the first and third or second and third methods may give identical results. The first method shows a smaller rate of depreciation in the earlier years, and a larger rate of depreciation in the later years, of the life history of the plant under consideration, than does the second method. In valuation the third method can be applied as readily as the others, but in accounting—in the operation of a water-works plant—the first two methods are the more specific, easier, and more certain of application. In operation it is generally more satisfactory to the stockholders to have an agreed and known percentage of first cost or of income charged off to depreciation annually, than to have lump sum amounts charged off as the service demands and the annual income or surplus may warrant. The former method of distribution should be no less accurate in a period of years, and should reduce the extremes of fluctuation in dividends. These general methods have been described so clearly elsewhere in the articles referred to herein, as to make extended comment unnecessary.

It may be said, however, that the work involved in calculating depreciation by the sinking-fund method is nominal when the probable useful life of the structure and rate of interest for the sinking fund have been determined, provided sinking fund tables are available.

Bond Formulas, Compound Interest, and Sinking Funds.—For the convenience of those who may have occasion to figure bond yields, interest, or sinking funds, when tables are not to be had, the following tables and formulas are presented. They were collated, arranged, and annotated for the writer several years ago by one of his assistant engineers, Frank H. Carter, Assoc. M. Am. Soc. C. E. The authority for and reference to the formula is given in each case.

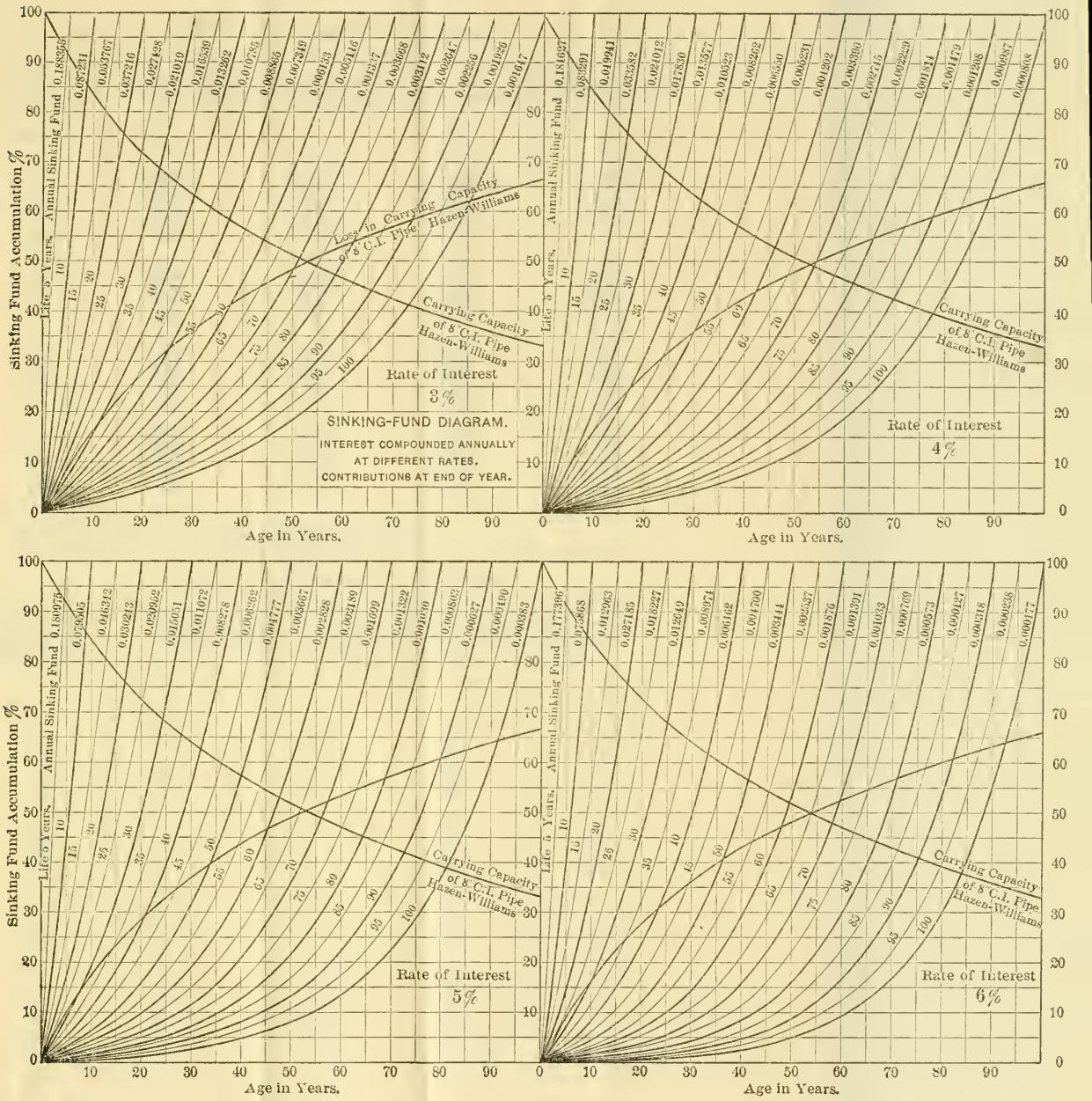
Sinking Fund Accumulation %
Annual Sinking Fund
Life 5 Years.
Loss in Carrying Capacity of 8" C.I. Pipe, Hazen-Williams
Carrying Capacity of 8" C.I. Pipe Hazen-Williams
Rate of Interest 3%
SINKING-FUND DIAGRAM.
INTEREST COMPOUNDED ANNUALLY AT DIFFERENT RATES.
CONTRIBUTIONS AT END OF YEAR.
Rate of Interest 4%
Rate of Interest 5%
Rate of Interest 6%
Age in Years.

TABLE 1.—Sinking-Fund Data.*

Life of structure.	Annual contribution to sinking-fund in percentage of first cost, with different assumed interest rates upon sinking-fund accumulations.			
Years.	3%	4%	5%	6%
5	18.8355%	18.4627%	18.0975%	17.7396%
10	8.7231	8.3291	7.9505	7.5868
15	5.3767	4.9941	4.6342	4.2963
20	3.7216	3.3582	3.0243	2.7185
25	2.7428	2.4012	2.0952	1.8227
30	2.1019	1.7830	1.5051	1.2649
35	1.6539	1.3577	1.1072	0.8971
40	1.3262	1.0523	0.8278	0.6462
45	1.0785	0.8262	0.6262	0.4700
50	0.8865	0.6450	0.4777	0.3444
55	0.7349	0.5231	0.3667	0.2537
60	0.6133	0.4202	0.2828	0.1876
65	0.5146	0.3390	0.2189	0.1391
70	0.4337	0.2745	0.1699	0.1033
75	0.3668	0.2229	0.1322	0.0769
80	0.3112	0.1814	0.1030	0.0573
85	0.2647	0.1479	0.0803	0.0427
90	0.2256	0.1208	0.0627	0.0318
95	0.1926	0.0987	0.0490	0.0238
100	0.1647	0.0808	0.0383	0.0177

Note.—Deposits at end of year compounded annually.
*Abstracted from "Robinsonian Bond and Investment Tables," J. Watts Robinson.

TABLE 2.—Sinking-Fund Data.*

Annual contribution to sinking-fund.	Approximate age at maturity or life of structure, with different assumed interest rates upon sinking-fund accumulations.			
%	3%	4%	5%	6%
¼	87 yrs.	72 yrs.	62 yrs.	55 yrs.
⅜	74 "	63 "	55 "	49 "
½	66 "	56 "	49 "	44 "
⅝	59 "	51 "	45 "	41 "
¾	54 "	47 "	42 "	38 "
⅞	50 "	44 "	39 "	35 "
1	47 "	41 "	37 "	33 "
1¼	41 "	37 "	33 "	30 "
1½	37 "	33 "	30 "	28 "
1¾	34 "	30 "	28 "	26 "
2	31 "	28 "	26 "	24 "
2½	27 "	24 "	23 "	21 "
3	23 "	22 "	20 "	19 "
3½	21 "	19 "	18 "	17 "
4	19 "	17 "	17 "	16 "
5	16 "	15 "	14 "	14 "
6	14 "	13 "	12 "	12 "
7	12 "	12 "	11 "	11 "
8	11 "	10 "	10 "	10 "
9	10 "	9 "	9 "	9 "
10	9 "	9 "	8 "	8 "
15	6 "	6 "	6 "	6 "
20	5 "	5 "	5 "	5 "

Note—Deposits at end of year compounded annually.
*Abstracted from "Robinsonian Bond and Investment Tables," J. Watts Robinson.

Net Return upon Bonds.—

B = face of bond,

R' = amount of \$1 for 1 year @ rate r',

P = price of bond,

n = years bond has yet to run,

r = rate of interest bond bears,

r' = rate of interest at which coupons are reinvested,

x = rate of interest which investment yields.

All rates of interest are here taken per year.

Common Method.—

$$P(1+x)^n = Br(1+r')^{n-1} + Br(1+r')^{n-2} + \ldots Br + B$$

$$= B + \frac{Br[(1+r')^n - 1]}{r'}$$

$$\therefore 1 + x = \left\{ \frac{B}{P} + \frac{Br[(1+r')^n - 1]}{Pr'} \right\}^{\frac{1}{n}}$$

$$1 + x = \left\{ \frac{Br' + Br(1+r')^n - Br}{Pr'} \right\}^{\frac{1}{n}} \quad \ldots\ldots\ldots\ldots (1)$$

(Wentworth's Algebra.)

The Robinsonian tables are not figured on the basis of the above formula, but as follows:*

Robinsonian Bond Values.—

$$(Br - Px)\frac{[(R')^n - 1]}{r'} + B = P$$

$$Br(R')^n - Br - \frac{Px[(R')^n - 1]}{r'} + Br' = Pr$$

$$\therefore P = \frac{B\left\{ r\left[(R')^n - 1\right] + r' \right\}}{r' + x\left\{(R')^n - 1\right\}} \quad \ldots\ldots\ldots\ldots (5)$$

(After Robinson.)

or, as J. Watts Robinson assumes r' at 4%:

$$P = \frac{B\left\{ r\left[1.04^n - 1\right] + 0.04 \right\}}{0.04 + x(1.04^n - 1)} \quad \ldots\ldots\ldots\ldots (2)$$

$$x = \frac{0.04(B - P) + Br(1.04^n - 1)}{P(1.04^n - 1)} \quad \ldots\ldots\ldots\ldots (3)$$

$$\text{or } x = \frac{r'(B - P) + Br\left[(1+r')^n - 1\right]}{P\left[(1+r')^n - 1\right]} \quad \ldots\ldots\ldots\ldots (4)$$

(After Robinson.)

*See page 19.

In the Robinsonian tables interest is compounded semi-annually.

Formulas 2 and 3 differ from all other bond value formulas in this: that the values are computed on the hypothesis that the reinvestments of interest necessary to compensate for the premium or discount at which a bond is bought are here invariably made at the rate of 4% per annum.

Compound Interest and Sinking Fund Formulas.—

B = face of bond,

P = principal, or present worth,

r = rate of interest on one dollar for one year,

R = amount of one dollar for one year,

n = number of years,

A = amount of P for n years,

q = number of times in year that interest is payable.

a_1 = annuity payable at beginning of year.

a_2 = annuity payable at end of year,

a_3 = annuity payable at the beginning of each year and at the end of last year,

S = amount of sinking fund at end of n years.

$A = P\left(1+\frac{r}{q}\right)^{qn}$; or if $q=1$ $\therefore A = PR^n$. Compound interest. (Wentworth's Algebra, p. 377.)

$P = \frac{A}{\left(1+\frac{r}{q}\right)^{qn}}$; or if $q=1$ $\therefore P = \frac{A}{R^n}$. Present worth.....(6) (Wentworth's Algebra, p. 377.)

$P = \frac{a_1(R^{n+1}-R)}{R^n(R-1)}$. Present worth of annuity payable at beginning of year.....(7) (F. H. C.)

$a_1 = \frac{P R^n (R-1)}{R^{n+1}-R}$. Annuity payable at beginning of year.....(8) (F. H. C.)

$P = \frac{a_2 (R^n-1)}{R^n(R-1)}$. Present worth of annuity payable at end of year.....(9) (Wells' Algebra, p. 381.)

$a_2 = \frac{P R^n (R-1)}{R^n-1}$. Annuity payable at end of year.....(10) (Wells' Algebra, p. 381.) (Wentworth's Algebra, p. 379.)

$S = \frac{a_1(R^{n+1}-R)}{R-1}$. Sinking fund, payment at beginning of year..(11) (After Frizell.)

$$a_1 = \frac{S\,(R-1)}{R^{n+1}-R}.$$ Annual payment made at beginning of year to establish sinking fund.....(12)
(After Frizell.)

$$S = \frac{a_2\,(R^n-1)}{R-1}.$$ Sinking fund, payment at end of year.....(13)
(After Frizell, p. 94.)

$$a_2 = \frac{S\,(R-1)}{R^n-1}.$$ Annual payment made at end of year to establish sinking fund.....(14)
(After Frizell, p. 94.)

$$P = \frac{a_2}{R-1}.$$ Present worth. Perpetual annuity.....(15)
(Wells' Algebra.)

$$P = \frac{a_2\,(R^n-1)}{R^{m+n}\,(R-1)}.$$ Present worth of an annuity to begin after m years and to continue for n years.....(16)
(Wells' Algebra.)

$$P = \frac{a_2}{R^m\,(R-1)}.$$ Present worth of perpetual annuity to begin after m years.....(17)
(Wells' Algebra.)

$$P = \frac{a_3\,(R^{n+1}-1)}{R^n\,(R-1)}.$$ Present worth annuity.....(18)

$$a_3 = \frac{PR^n\,(R-1)}{R^{n+1}-1}.$$ Annuity from P.....(19)

$$S = \frac{a_3\,(R^{n+1}-1)}{R-1}.$$ Sinking fund.....(20)

$$a_3 = \frac{S\,(R-1)}{R^{n+1}-1}.$$ Annual payment to establish sinking fund in n years with $n+1$ payments.....(21)
(After Robinsonian Tables.)

The annual payments to be made at the beginning of each year and at the end of the last year, or $n+1$ payments will be made.

Method of Comparing Economy of Structures.—*

A = first cost,
X = repairs at intervals of s years,
s = length of time between repairs,
n = life of structure,
D = value at which plant may be sold at end of n years,
C = capital involved at present,
r = rate of interest,
q = number of times in 1 year that interest is payable.

$$C = A + \frac{X}{\left[\left(1+\frac{r}{q}\right)^{qs}-1\right]} + \frac{A-D}{\left[\left(1+\frac{r}{q}\right)^{qn}-1\right]} \quad \text{.....(22)}$$

* G. F. Swain, M. Am. Soc. C. E., *Journal*, N. E. W. W. Assoc., Vol. II, No. 3, March, 1888, p. 32.

Proof of Formula 22:

By Formula 15,

$$P = \frac{a_2}{R-1}, \text{ and } a_2 = P(R-1)$$

By Formula 13,

$$X \text{ or } S = \frac{a_2(R^n-1)}{R-1} = \frac{P(R-1)(R^n-1)}{R-1} = C'\left[\left(1+\frac{r}{q}\right)^{qs}-1\right]$$

$$C' = \frac{X}{\left[\left(1+\frac{r}{q}\right)^{qs}-1\right]}.$$

Formula 22 is based upon assumed permanency of investment. If, on the other hand, it is desired to retire the investment at the end of n years, Formula 22 should be modified by taking out of the denominator of the third term of the equation (—1) and reducing, which will leave the formula in the following form:

$$C = A + \frac{X}{\left[\left(1+\frac{r}{q}\right)^{qs}-1\right]} + \frac{A-D-C'}{\left(1+\frac{r}{q}\right)^{qs}} \quad \ldots\ldots\ldots\ldots (23)$$

If the repairs are to be made annually, or s be made equal to unity, Formula 23 reduces to the following terms:

$$C = A + \frac{a_2\left[\left(1+\frac{r}{q}\right)^{qn}-1\right]}{\left[\left(1+\frac{r}{q}\right)^{qn}\left(\frac{r}{q}\right)^{q}\right]} + \frac{A-D}{\left(1+\frac{r}{q}\right)^{qn}} \quad \ldots\ldots\ldots (24)$$

The references consulted and referred to in the foregoing are:

Wells' "College Algebra," Edition of 1890.

Wentworth's "Complete Algebra," Edition of 1888.

Frizell's "Water Power," Third Edition, First Thousand.

Journal of the New England Water Works Association, Vol. II, No. 3, March, 1888.

"Robinsonian Bond and Investment Tables," Second Edition.

As to the period of life of different portions of the water-works plant, opinions vary with the views and experience of the engineer or man rendering judgment, and many local circumstances and conditions affect the efficient or useful life of the structure and hence the depreciation very materially. Generally, however, the useful life of those structures has been assumed by different engineers, testifying in water-

works valuation cases, to lie between the general limits given in Table 3.

TABLE 3.

	Useful life.	Annual Contribution to Depreciation Account or Sinking Fund in Percentage of Cost. Compounded Annually at 5 Per Cent.	
		Precise figures.	Approximate figures.
Reservoirs	50-100 years*	0.4777%-0.0383%	½-0%
Standpipes	25- 40 "	2.0952%-0.8278%	2 -1%
Masonry buildings	40- 50 "	0.8278%-0.4777%	1 - ½%
Wooden buildings	20- 50 "	3.0243%-0.4777%	3 -1%
Cast-iron pipe of large diameter	50- 75 "	0.4777%-0.1322%	¾- ¼%
Cast-iron pipe of small diameter	20- 40 "	3.0243%-0.8278%	3 - ¾%
Steel pipe	25- 50 "	2.0952%-0.4777%	2 - ¾%
Wood-stave pipe	20- 30 "	3.0243%-1.5051%	3 -2%
Wrought-iron service pipe	15- 30 "	4.6342%-1.5051%	5 -2%
Meters	20- 30 "	3.0243%-1.5051%	3 -2%
Hydrants	40- 50 "	0.8278%-0.4777%	1 - ½%
Gates	40- 50 "	0.8278%-0.4777%	1 - ½%
Pumping and auxiliary machinery	20- 30 "	3.0243%-1.5051%	4 -2%
Steam engines	15- 25 "	4.6342%-2.0952%	5 -3%
Boilers	12- 16 "	6.2825%-4.2270%	6 -4%
Electrical machinery	20- 30 "	3.0243%-1.5051%	4 -2%
Average for entire plant (gravity system)			1% to ½%
" " " " (pumping system)			2% to 1½%

* Except where subject to heavy deposit of silt.

The figures for depreciation in Table 3 may be largely exceeded. In a rapidly growing, young community, the efficient life of the structure may be very short; pumps may be outgrown and discarded within 5, instead of 20 to 30, years' time; pipe may be replaced in 10 years or even less, etc.; and yet reasonable prudence may have been exercised in the original design; but the promise of development, or direction of growth, or character of the demands of the service, may have been too uncertain to warrant larger outlay and more liberal design in the original construction.

In principle, therefore, every water company should "write off" or deduct annually from its assets a sum which will, at least, cover this depreciation, and the writer is of the opinion that, inasmuch as this allowance has to be made in advance of the development of the facts and testing of the structure, a liberal policy should be adopted in order to ensure reasonably the future integrity of the capital invested in the plant in so far as this phase of operation is concerned.

The total annual depreciation will generally be found to lie between the following limits:

For gravity works from ½% to 1%.
" pumping " " 1½% " 2%

of original cost, though considerable variations from these limits will be found, owing to the abnormally high functional depreciation resulting from errors in judgment, the development of structural weakness, faulty design, or from an over-niggardly policy in original construction, and to a multiplicity of other causes.

Sinking Fund as a Substitute for Depreciation.—As a matter of fact, while few municipalities have recognized this depreciation or perhaps even considered the underlying theory of it, they have, in effect, made allowance for it in the sinking-fund provisions of the bonded debt, and it may be added that the sinking-fund requirements have usually been in excess of the necessary allowance for depreciation, as a result of the assumption of a shorter life for the bonds than the actual life of the structures covered by them, though, perhaps, there is a tendency to-day to issue longer term bonds—the terms of which in some cases exceed the probable life of the structure. This practice is to be condemned unless the sinking-fund requirements correct this evil; even then this practice appears illogical.

Renewals.—Engineers are somewhat divided in opinion as to the necessity of charging off to depreciation any portion of renewals involving a betterment of the service. Some contend that renewals involving betterments of service—there being no difference of opinion, of course, in regard to renewals which are mere replacements of existing structures—should be charged in part only to construction; or, in other words, that the value in the original structure not previously written off in depreciation should be deducted from the construction account simultaneously with the addition to it of the increment of value in the renewal represented by the betterment of the service; while other engineers contend that the entire cost of the element of the renewal representing the betterment of the service, should be charged to construction account, without any deduction on account of the remaining value in the original structure which has been sacrificed or lost, upon the theory that the betterment is demanded by increased business or larger requirements, and that hence the new business should carry the entire burden of the larger debt thus created. To take a concrete example, let us suppose that the growing needs of a community necessitate the relaying of a 6-in. pipe with a 12-in. pipe. Upon the first theory, the water-works company would be entitled to charge to construction account only the difference between the entire cost of the 12-in. pipe and the remaining value (*i. e.,* not yet written

off) in the 6-in. pipe, the rest being charged to renewals in offset to depreciation; upon the second theory, the entire cost of the 12-in. pipe might be charged to construction account, upon the theory that the 6-in. pipe was still adequate to meet the requirements for which it was laid, and that the larger main was required by the greater demands of added business which should therefore carry its entire cost. Furthermore, say exponents of the second theory, the saving in interest upon the smaller original structure during its life, as compared with the larger structure had it been built, has more than covered the cost of the smaller structure; to which it is replied, that this fact has no significance beyond pointing the limits of rational design.

Certainly the first theory is the more conservative, and safer from the point of view of the bondholder or owner of the property.

Land, Water Rights, Etc.

Real estate must, of course, be valued on the basis of its market value and not upon the foregoing rules.

Monopoly Value of Land and Water Rights.—While the Maine Courts have laid down the rule that the public is entitled to the most advantageous development, it does not appear that consideration shall not be given to the fact that in some cases what may be loosely termed a monopoly value may attach to a property of this character. Take the case, for instance, of a reservoir site, where several alternate and equally advantageous sites are available, no particular value can attach to any one property in excess of its market value. If, on the other hand, there be but one site which can be used for this purpose without going to great expense in obtaining another, additional value in excess of the market value would appear to inhere in this property. Under some circumstances, perhaps, the limit of this value might be equivalent to a saving in construction upon this site, as compared with a less favorable site, or with the cost of an alternate method of accomplishing the same results, or with the additional cost of modifications in the design of the plant to meet the same ends. Generally speaking, however, this increment in value will be measured not in the manner stated, but by the additional sum of money which a purchaser would have been likely to give for this property when he purchased it, in advance of the construction of the works, in view of the possible use of

this property by the company at a later date. A prospective purchaser would undoubtedly pay a larger sum for property with such inherent possibilities, but, on the other hand, if there was a possibility of his having to hold the land for a considerable period of years, he might consider this additional speculative value as small.

Commodity Value.

The idea of attempting to value water delivered through a pipe system as a commodity, appears to be fundamentally wrong except under such conditions as might prevail in a desert or where water is not to be found locally, or within reasonable distance for transmission by pipe system, and the writer has certainly not chanced to hear of any case in which valuation of water as a commodity has had standing. To state that water, where the supply of potable and suitable water is manifestly in excess of present or prospective needs of the community, can have value for many and diverse uses as a true commodity, appears contrary to fact. The value of the water to the community, aside from possible uses for the development of power, is created solely by the demand for water supply for public, domestic and manufacturing uses in the particular community under question, and that, moreover, in a limited quantity. It has value only to the limit of the demand or market for it; in short, the only market for this water is a local one, and if there be several possible alternative sources of supply, the water actually in use derives its value, not from the fact that it is a commodity, but from the existence of the franchise under which the company is operating and from what might be otherwise considered thereunder as monopoly value in water supply, that is, the right to sell water in a given community for profit, usually under non-competitive conditions. The water has value to the company, not solely from the fact of its existence, but also from the company's charter or franchise right to distribute it and to collect toll; therefore, the commodity theory is weak in that it entirely overlooks the duty of the company, under common law rules and the Maine decisions, to furnish water service to the consumer at a price that is fair in any event. Far from being a commodity value, this value is predicated upon the fact of service and worth to the consumer, and is fundamentally dependent upon the franchise which gives monopolistic value to the water by prescribing non-competitive conditions.

Liability of Water Companies for Fire Loss Due to Inefficient Service.

A consideration which, heretofore, probably has had little weight in water-works valuation, but which may depreciate properties of this character permanently, is that of the financial liability of water companies for loss incurred by fire, in which inadequate fire service can be proven. Court decisions have been numerous upon both sides of this question, but the weight of decisions has—before the Greensboro decision—been largely in favor of the water companies, upon the technical ground that, inasmuch as the water consumers were not parties to the contract of the water company to furnish water to the city for fire protection (or, to use a safer word, water for fire service), they could not sue the water company for breach of contract. Judge Brewer of the Supreme Court in the appealed Greensboro Water Company decision,* however, has taken the view of water-company liability based upon the broad ground of negligence, a decision of far-reaching importance to many water companies, suggesting the need of the greatest care in the preparation and wording of fire-service contracts.

Going Concern Value.

The Maine Court has ruled that the "going concern" or "established business" is an element of structure value. It may be defined as the cost of establishing, up to the level of the net income of the old plant at the date of taking, the business of a similar new plant (but not of a more perfect system which the city might build), which is supposed to begin operation upon the date of the taking, the old plant going out of business at the same moment. Or, to put the same thing in another way, it is the measure of the greater value (at the date of taking) of an old, established plant, over a similar new plant completed and ready for operation upon the date of taking. Or, to put the same thing in still another way, it is the measure of the cost of developing the business of a new plant to a point coincident with the net income, upon the date of taking, of the old plant.

Hence the "going concern" or "established business" element of value—subject to the fairness of the rates and the character of the service—depends directly upon the net income or earning capacity

*Guardian Trust & Deposit Company *vs.* Fisher, 200 U. S., p. 57, Brewer, 115; Federal Reporter, 184.

of the works at the date of taking, and there does not appear to be justification for including in this value, as some experts in water-works valuation have done, consideration of the increment in net annual income in the period of years after the date of taking, during which the business is being established. The latter (increment) clearly pertains to franchise and not to going concern value. As previously stated, the going concern value is only one element of value, included in the total value found by capitalization or consideration of the net income under reasonable rates. To add the going concern value to the total value would involve double payment for the same thing, but in the case of the plant the franchise of which has expired, the going concern value must usually be calculated and added to the reproduction cost less depreciation thereon to date, in order to determine the value of the plant.

In passing it may be of interest to suggest certain underlying principles bearing upon the going concern element of value. In the course of their development and life history most water-works plants pass through the following phases:

1.—That of the plant which has not been operated for a sufficiently long period of years to develop its normal revenue or rate of growth, or, in other words, that has not passed through the formative period.

2.—That of the plant which has passed through the formative period, but which has not yet made good, through its increasing revenues, the losses sustained in the early years of the formative period.

3.—That of the plant in which the going concern has been established, and the losses during the formative period have been made good.

1.—If the works be taken by the city while they are still in the formative period, or period of business development, it is clear that the net revenue does not furnish an equitable means of determining the value of the property, since there is no net revenue, and this fact should be given due weight. If the owner of the works should attempt to sell his plant during this period, the purchaser or investor would probably give small recognition to this fact; the sale would be in effect in the nature of a forced sale, and hence the owner would probably

not derive a reasonable return for his property, even from a willing purchaser. On the other hand, if the valuation of the works is based upon the taking by the municipality under right of eminent domain and hence upon their value to the owners, subject to limitation of reasonable rates and reasonably good and efficient service, as it must be under the Maine decisions, this fact must be given due consideration.

2.—If the works are bought immediately at the end of the formative period, but while the owner is still carrying the accumulated losses of the early years, this fact should be given due weight in arriving at a valuation based upon the earning capacity of the plant when taken by the city. The same idea might be stated differently by saying that, at such a time, the seller would not be a willing seller but a forced seller. It cannot be doubted that if the works should be purchased by an investor or a willing buyer at that time, he would make no allowance to the owner for any losses incurred by him in the early years of operation, except in so far as prospective earnings might warrant some small consideration, for the value would be derived and the market price be paid as a result of the going concern, the established business, and the earning capacity, and not as a result or measure of the works having passed the early hazard period. In the case of a plant taken under the right of eminent domain or legislative authority, however, the valuation must be made on a basis of the value of the works to the owner subject to the limitations of reasonable rates and service, in which case the fact cited above should be given due weight, and, in case of fair-rates suit, due consideration should be given, in a study of the rates, to the fact that the owner had not been reimbursed up to that time for the early losses, and this condition would result in the postponement of the day when the community might justly expect a reduction in the rates for water service.

3.—Finally, in the case in which it is assumed that the company has been reimbursed, through the agency of the rates, for the losses during the early years of development, the full value of the going concern has been established, and the owner has received adequate return upon his property up to date of taking; and it may be added that a new situation has arisen, under which the rates, previously equitable, are beginning to be unjust to the community, unless increased extensions and improvements to the property or service make

a drain upon the revenue commensurate with the surplus earnings which had previously been applied to the liquidation of the early hazard debt, or the losses incurred in establishing the business.

If it is a fact that after a reasonable period of growth, which period could not well exceed ten years, and, in many cases, a less period, the normal income of the company has not been developed, and it is still being operated at a loss, no other conclusion can be drawn than that the owner of the property has voluntarily taken upon his shoulders a losing contract with the community, the penalty of which he must, under the terms of that contract, pay, without increase in rates and with disadvantage to himself, in case he should attempt to sell the property. As owner he was not obliged to enter into contract with the community to supply water to it, or to accept the franchise which it offered, but having done so, under the law of contracts, he must suffer the consequences to the limit of his financial ability. These losses, under the circumstances cited, would be the measure of the price which the owner would have to pay for the privilege of the continued enjoyment of his franchise.

In the writer's experience, the going concern value has usually been found to be between the net and the gross income of the plant for a period of one year (at the date of taking). It may be largely affected, however, by the period required for the development of the business.

Franchise Value.

The franchise rights usually cover fundamentally the right to take and develop sources of water supply, condemn property necessary for the use of the water-works, use the streets, highways and public places, supply water to consumers for domestic and commercial purposes, and to collect tolls or water rates therefor.

Its value cannot generally be determined directly. If desired, it must be obtained by eliminating from the total value of the property the remaining elements of value, if this is possible.

The Measure of Fair Rates.

Much has been said by counsel in different cases upon the unreasonableness of the rates, with but little effect, however, as no measure has been given of the extent or degree of the unreasonableness or of its effect upon the consumers individually or collectively.

Fair rates cannot be determined by comparison of water rates in

neighboring or similar communities, since identical conditions probably never exist, and weight cannot be given readily or intelligently to the different causes which might affect them. The Court has always recognized this fact and wisely excluded direct comparison of rates. Nevertheless, it is probably true that rates in similar communities do have weight in limiting the magnitude of the rates.

It has remained for Judge Savage to furnish the proper gauge or yard-stick with which to test the fairness of the rates—the worth of the service to the consumer, as well as the fair return to the water company.*

Here is a frank recognition of the obligations of the public servant on the one hand, and of its rights on the other. The water-works corporation is not engaged in a private business for profit, limited only by competition and the laws of supply and demand, but in the performance of a public duty, subject to the requirements of efficient service and fair rates, and privileged to make profit under non-competitive conditions. The property of this quasi-municipal corporation, therefore, cannot have, or be valued upon the basis of, "market value." In appraisal, its value, under the Maine opinions, must be the "value to the owner," subject, however, to the limitations of the efficiency and the worth of the service to the consumer, or, in other words, of fair rates for water service of the character furnished.

Obviously, it cannot be expected that the cost of this service will not exceed the cost to the public of supplying itself; for it is reasonable to suppose that, inasmuch as the public elected for one reason or another to grant the franchise for water-works to a corporation, it was willing to pay somewhat higher rates than those at which it might have supplied itself. This excess is a matter of judgment in the light of all the existing facts, but the Court calls attention to the need for caution in applying this rule, since the company, in accepting the franchise, voluntarily chose to take whatever hazard there was in the business; and further holds that whatever the consequences or loss to the owner, the rates must not, in any event, exceed the worth of the service to the consumer.

Heath's Method of Measuring Fair Rates and Value.—As counsel aptly put it, one cannot value without rating, and once one has determined the fair rates for a given plant, one has valued it.

The method of rating and valuation outlined herein was first

* See 99 Maine, 371, Pars. 6, 7, 14 and 13.

developed and used, so far as the writer knows, by Hon. Herbert M. Heath, of Augusta, Maine, in the suit of the Kittery (Maine) Water District *vs.* the Agamenticus Water Company, in November, 1907, and later in two other water-works valuation suits—Livermore Falls Water District *vs.* Livermore Falls Water Company, heard in November, 1907, and the Portland (Maine) Water District *vs.* the Portland Water Company, the Standish Water and Construction Company, the Gorham Water Company and the Foreside Water Company, heard in February to May, 1908. Mr. Heath had previously had considerable experience in water-works litigation and valuation, and had given much study in his wide practice, as a corporation lawyer in New England, to the important economic questions involved in the relations of the quasi-municipal or public service corporations to the public; but it was not until the Brunswick decision that this principle of the worth of the service to the consumer was laid down by the Court, and first put to practical application by Mr. Heath. As the writer had the pleasure of assisting Mr. Heath in working up his theory (or method of applying this principle) and the tabulations for his argument in all three of the above-mentioned cases (Kittery, Livermore Falls, and Portland), he may be permitted, perhaps, to outline it.

The theory was probably the outcome of a critical study, by Mr. Heath, of the rating question, of the rules of valuation and fair rates laid down by Judge Savage in the Waterville and the Brunswick opinions, of the previous valuation litigation in Maine and elsewhere, of the English methods which governed the valuation of the London water companies; and of his interest in the broad economic principles and questions of public policy involved in the relations of quasi-municipal corporations to the public.

Value, Mr. Heath holds, must be based upon cost—be the latter reproduction cost, based upon prices prevailing on or about the date of taking; or reproduction cost based upon fair average prices for a considerable period of years; or original cost; or something between these three—upon cost plus a profit which shall be limited, upon the one hand, by what may be needed to induce investment in and active competition for the privilege of operating public service corporations, and, upon the other, by the cost at which the public might serve itself equally efficiently plus the profit which the public might be willing to allow to a corporation for doing the work and thus relieving it of the necessity and, perhaps, risk of serving itself.

Starting with this fundamental idea, that the public service corporation is entitled not only to the reasonable cost of furnishing the service, but also to a reasonable profit thereon (assuming always that the works can earn the necessary income to admit of this), we come logically to a consideration of the principal elements or factors to be covered by the rates, and hence to what might be termed the maximum lawful income for the given plant under existing circumstances—for any increase in earnings beyond this point should, by the law of diminishing returns, revert or inure, sooner or later, to the public, in one form or another. To say that, in a consideration of the lawful annual income to be derived from the rates, no allowance, beyond operating expenses, depreciation, and a reasonable return upon invested capital, should be made to the builder or owner of the works, would be contrary to public policy and expediency. Under such conditions capital could not be induced to embark in such ventures, and progress might be seriously handicapped in many communities.

Elements to be Covered by Lawful Rates.—Subject to the limitation of the Court ruling, that the rates shall be reasonable to the individual as well as to the community as a whole, and to the practical business possibilities involved in the case or the willingness of the people to become water takers at the established rates, the corporation is entitled to fix its rates so as to earn:

First.—Full operating expenses, including therein all necessary repairs to keep the plant in good condition.

Second.—A depreciation or renewal fund, which shall always keep intact the capital invested, by replacement through this fund of the worn out or discarded parts of the plant.

Third.—Such a rate of interest upon the invested capital as will correspond to the degree of hazard involved in the investment.

Fourth.—Interest upon the reasonable profit increment (discussed in the following pages) which is assumed as compensation for undertaking this public service.

Fifth.—A sinking fund, if approved by the public. The question as to whether a sinking fund should or should not also be earned and allowed is perhaps a "local-option" question, inasmuch as it merely affects the distribution of the burden of construction, and not its amount.

If a sinking fund be added, the item of interest upon invested capital included above would be omitted, of course, after the amortization of the debt of construction by the sinking fund. If the annual contribution to the sinking fund be large, the construction debt will be quickly paid, but the present burden will be heavy upon the consumer; if it is small, the period will be lengthened and the burden decreased. Views differ upon this question, which is after all one of sound public policy. The occasional needs or burdens growing out of war, fire, earthquake, flood, or other disaster, which have befallen cities from time to time, dictate or at least indicate the wisdom of letting each generation bear its own burdens and of making regular contribution to a sinking fund, which will wipe out the construction debt within a reasonable period of time, such as 20 to 40 years.

Referring now in greater detail to these elemental considerations in determining rates, the "operating expenses" need no comment, and "depreciation" has already been discussed;* the "rate of interest," the "base upon which it is to be figured," and the "reasonable profit" are not so easy of determination.

The Rate of Interest.—This rate should not be that at which the city or town could borrow money, even upon its water-works securities, as the community's credit rather than the actual hazard would be reflected in this rate; neither should the rate at which the company has borrowed money be controlling, though it may be confirmatory evidence. The customary rate of interest prevailing upon securities or loans of equal security or hazard should govern. In New England, rates of 5 to 6% may be considered, perhaps, as typical of average conditions in recent years.

Under the method of valuation discussed herein, the rate of interest actually adopted and used makes no difference in the final valuation of a plant which is earning its maximum lawful return. It pertains only to the rating, to the determination of the maximum lawful income from the given investment under existing conditions. As far as the value goes, it makes no difference whether the rate be assumed to be 5 or 10%, for having once determined the lawful, annual income (based upon this given rate), the value may be obtained by capitalizing this income at the assumed rate of interest, or, what is exactly the same thing, having determined the base on which interest and profit are to

* See pages 16 to 26.

be calculated (in the building up of the lawful income), the value is obtained by increasing this base by the profit increment, or ratio, to be allowed for assuming this public duty or performing this public service. This subject is further discussed under a later paragraph upon "Reasonable Profit."*

The Base on Which the Interest is to be Calculated.—This factor requires the most careful thought. Should interest be computed, first, upon the reproduction cost at the time under consideration; or second, upon a fair average reproduction cost during a period of years long enough to give normal or mean business conditions; or third, upon actual cost of the works? The Courts have prescribed the first, as one of the fundamental considerations of value, but they have also attached great value to the last. The second method has always seemed to the writer, on the whole, the most equitable of the three.

In figuring the cost to the public of supplying its own service, this cost may be based upon the reproduction cost of the plant, upon the theory that the rating is made as of the date of taking, and current prices, therefore, should control, or upon the original cost, on the theory that the company is entitled to a consideration of its actual investment. Each method has its objections, the former, in that in a period of exceedingly high, if not actually inflated, prices for materials and labor, such as that through which we have passed recently, the reproduction cost would be abnormally high and as injurious and unfair to the public as would be the conditions to the company under abnormally low prices; the latter, in that the town is no more entitled to the benefit of the particular advantages accruing to the company for unusual good fortune, or economy of or shrewdness in construction, than it is to be held responsible for any negligence, bad judgment, or lack of prudence, foresight or economy on the part of the company. There would seem to be some justice, therefore, in basing the cost-to-the-public-of-furnishing-the-service (as a gauge of fair rates to the company) rather upon what might be termed the fair average prices for a period of years, than upon the actual reproduction or original costs, though the Maine Court has said that reproduction cost should be figured on actual prices and that the owner is entitled to any appreciation, or must suffer the loss due to any depreciation, growing out of change in prices since the original construction.

* See page 37.

In the case of a limited and expiring franchise, too, the reproduction cost, as of that date, decreased by the depreciation to date and increased by the going concern value, would seem to furnish the proper basis for valuation under existing laws, though, in equity, it would appear fairer to compute its reproduction cost on average prices prevailing over a past period of years, rather than upon actual prices at the time under question.

The Reasonable Profit Increment or Allowance.—The reasonable ratio or excess of profit over cost to be allowed to the public service or quasi-municipal corporation is largely a question of good sound judgment based on an intimate knowledge of all the facts and the local circumstances bearing upon the case in question. Generally speaking, this ultimate ratio, corresponding to the development of the maximum lawful income for any given investment, may lie between 25 and 50%, but even these limits may be exceeded.

With good, energetic and thrifty management, the maximum development and profit increment will be reached early in the history of the plant and may be maintained throughout its life; with bad management, its development will be delayed or may never be reached, and even the original investment or capital may be impaired or lost.

The profit ratio, as indeed the interest rate, is thus dependent on the character and stage of development of the plant; on the magnitude of the project; the character of the community, its size, rate and permanence of growth, wealth, comparative safety, stability, prosperity, liberality, nationality; on the attitude of the community and of the courts; and on the character of franchise; physical environment as affecting possible competition; the character and efficiency of the physical plant; the physical risks; the provision for future needs, etc.

In this connection attention should be called to four considerations, sometimes lost sight of, which should be borne in mind in reviewing past operations of any corporation with reference to present valuation or rating:

First.—The difference in the water-works standards of to-day, as compared with those of the past.

Second.—The change in attitude of the public toward quasi-municipal corporations, the progressively closer public supervision of their operations, and the greater limitations put upon them.

Third.—The extent to which the past operations and earnings of the company, at rates which have not been challenged for a long period of years, may be presumptive evidence of their supposed fairness from the public point of view regardless of actual cost to the company of furnishing the service, and even though they may show to the company an unreasonably large profit upon the actual capital invested.

Fourth.—The effect of past determination of value or of fair rates by legal or judicial procedure after agitation of these questions.

The third consideration is one of the most difficult to handle, for, on one hand, innocent investors who have purchased water company securities upon a basis of their earning capacity or market value, under rates long in force and never called into question, are ranged against the public with its right to demand efficient service at rates that are not exorbitant to the water consumers, either individually or collectively, and that shall show to the company and its investors no more than a reasonable profit upon its property.

If the property or rates have been subject to controversy and legal adjudication prior to the valuation, the results reached at that time would seem to furnish a suitable starting point for subsequent valuation, and, perhaps, prevent the possible oversight of the elements referred to.

Disposition of Excessive Rates.—If, judged by the worth of the service to the consumer, the rates are excessive, the excess should apply to reduction in rates, betterment of service if the latter be needed, or to reduction in debt; and any increase in net annual income (over and above the demands of increased operating, maintenance, or fixed charges growing out of additional investment) should apply to the same end—reduction of rates; or, as Mr. Heath, Counsel for the Livermore Falls Water District, aptly put it, in his final argument:

"* * * Any additional net income derivable here would be excessive; and we would approach that stage in rating when, as they call it in the books, under the law of increasing returns, the new additional net income should inure to the benefit of the public served, * * *"

and Mr. Heath went on further to draw a parallel with the history of the railroads of the United States which, with increasing tonnage, have been able to reduce their rates enormously.

"This is but the natural operation of the economic law in public channels, a recognition of it by men who knew and understood that they were public servants; and that as the business increased the public got the benefit of it.

"* * * We have shown that the day has come in the history of this plant when the future increment in income belongs to the people by way of reduction of rates, a just principle, Mr. Chairman, because a certain amount having been invested by somebody, having built a good plant, having covered the area, then there should be an hour some time in the history of this and all water companies when they reach the maximum net income that is lawfully derivable, holdable and keepable from that plant; and when you go beyond that, the hour of the people has come to receive proper reductions in their rates. Now assuming that I am right in these propositions, let us view the matter from the standpoint of the element of fairness to the company. The Court has said * * * in this Brunswick decision, * * * that the amount of money actually and wisely expended is a primary consideration in this matter of a fair return; and it ought to be, because the money invested ought to be protected by the courts and legislature, so far as can be done with justice to the public; and if it be that they can get a fair return upon money originally expended, at the same time doing it without oppressing the people, and not exceeding the worth of the service to the community, they ought to have it—otherwise we would have no water-works."

The owner of the water-works benefits not only by the allowance to him of a return in excess of the cost to the community of furnishing a like service, but also by the greater security of his investment growing out of the just recognition of these principles.

Extracts from Argument of Hon. Herbert M. Heath, Counsel for Water District in Portland, Maine, Case, Upon Method of Valuation, Reasonable Profit Ratio, and Rate of Interest to be Allowed Upon Capital Used.

Mr. Heath outlined the foregoing method of valuation so clearly in his argument for the Portland Water District, May, 1908, that a portion of his argument is here quoted:

Extract from Outline of Method of Valuation.

* * * * * *

"The method therefore assumes the application of the valuation rules of the Waterville and Brunswick cases to this plant and its franchises, as now developed, the reproduction cost standing as the equivalent of the capital employed, earning the maximum profit law-

fully derivable from it, with a charter giving the right to earn from takers the full profit ordinarily derivable from all its service, with its present lawful profit assured, with no depreciation, the quality of the service unattackable, the plant now fit to meet reasonable requirements of the present and future, efficient in every part, having kept pace with and reasonably anticipated municipal growth, with no acts of its own permanently depreciating its franchises, with no property not reasonably necessary to the service, with no structure unreasonably expensive, and, finally, with an assumption that the works were built prudently.

"A valuation so reached treats the property by assigning to it full value for all its characteristics of value, as a structure, as a structure that is a going concern, and as a structure with a right to continue the use of its franchises, that is, to earn the maximum profit derivable from it by law without new development. The result must necessarily be the largest possible valuation assignable to the property and franchises, due allowance, if any, to be made later for new development.

"After reaching such a result, we shall then contend that it ought to be reduced because of the following depreciating elements:

"1. That the customers of the company cannot lawfully be made to bear any part of the burden of the worth of the free municipal service.

"2. That the plant has suffered in value from physical depreciation.

"3. That the quality of the service rendered is below the reasonable standard required by the charter.

"4. That the plant is not now fit to meet reasonable requirements in the present and future, is inefficient in whole and in parts, and that it has not kept pace with or reasonably anticipated municipal growth.

"5. That by its transactions with the Standish Water and Construction Company, and the distribution of the stock received for the perpetual water supply, the Portland Water Company has seriously and permanently lessened the normal enhancing power of its franchise characteristic of value, and thereby materially and heavily diminished the value of its property and franchises.

"6. That its transactions with the Foreside Water Company have likewise permanently diminished the value of its property and franchises.

"7. That the lease of the Sebago basin was not reasonably necessary to the service.

"8. That various structures were unreasonably expensive and were not built prudently.

"9. That, finally, due consideration must be had of the original cost of the plant in use, and the final result reduced as fairness to the company and to the public may require.

"Thereafterward, study must be had of the value, if any, of the right of the Company to extend the use of its franchises by new investment and, if the facts require it, addition be made therefor.

"Next, should be discussed and properly treated the claims of the Company for additional value for the Bramhall and Munjoy Sites, the services, the public hydrants, and the Warren Contracts. All these elements we shall claim to be without value.

"Then to reach the award must be added the agreed value of the tools and supplies, the value of the Martyr Street Lot, the allowance (if any) for maps and plans, and the values of the stocks of the Gorham Water Company, the Foreside Water Company, the Presumpscot Water Power Company, the Saccarappa Aqueduct Company and the Munjoy Land Company.

"The result will be the award to the Portland Water Company, as we claim it ought to be.

"We wish, at the start, to emphasize the statement that any result reached in this case by starting with the reproduction cost as a basic factor must necessarily be too high. The prices of the reconstruction period involved in the conception of building this plant for delivery on January 1, 1908, were abnormally high.

"Care was taken in the Waterville case, p. 207, to say that caution must be used if it appeared that the works were originally built when prevailing prices were high so that actual cost might exceed present value. The suggestion is equally forceful in using the element of replacement cost computed as of a period of abnormally high prices. And the Court took great pains to emphasize the importance of original cost in its relation not only to present value but equally so in the determination of the maximum profit legally derivable from the property.

"Great care was also used throughout both the Waterville and Brunswick cases to say that, in arriving at present value, neither original cost nor reproduction cost should outweigh the other, but that both elements should be carefully considered.

"The practicable method seems to me to estimate the award first by using the reproduction cost as the basic factor and next to so estimate it by using the original cost, leaving it to the Court to work out the truth somewhere between the two, as justice may require.

"The method proposed ultimately appraises the system in use, in its present condition and with its present efficiency. (Waterville case, p. 216.)

"It rejects the capitalization of profits, condemned as improper in the Waterville case.

"It does not undertake to separate the award into structure-value, going concern value and franchise value, condemned in the Brunswick case as inherently impossible.

"A method that completely values property and franchises as a unit values the property as a structure, as a structure in use as a going concern, and as a structure which may rightfully continue to be used as a going concern structure. (Brunswick, p. 376.) The owner thereby receives full and fair value and the just compensation required by law.

"Throughout the discussion it must be remembered that while the present depreciation is heavy, due to physical wear and tear and to inefficiency calling for new investment to an amount so large as to seriously lessen present value, the Company has had net profits enough during the past forty years to have given to it a full fair return from the very first year and to have also accumulated from its remaining profits a depreciation fund large enough to meet every dollar of the depreciation now due to deterioration and present inefficiency due to the fact that the territory served has outgrown the capacity of the plant as it has three times before in its history.

"Of this accumulated depreciation fund the Company now has on hand cash assets of the value of nearly $300 000, all of which it retains under the taking act. It has earned rates in the past upon the theory that this fund was available to make good all depreciation due to deterioration of plant or to loss in value of any part of its system due to growth of the public needs. The fund on hand is the lawful and legitimate accumulation of the depreciation allowances with which it properly loaded its rates. If it is to keep it, the Company cannot complain that the value of its plant should be lessened, in the award, to the extent of the depreciation, whatever it may be.

"In addition to this $300 000 (approximately stated) the Company has, as above stated, also collected from its takers in the past in addition to a full fair return from Jan. 1, 1870, enough to meet every dollar of present depreciation, physical, functional or otherwise. This we will show from the books before the case closes. Instead of keeping it to meet death of capital in the public service it has divided it. It has been dividing its plant for twenty years, as do so many corporations greedy for dividends on stock that represents no investment. We shall show later that this Company has received in rates enough so that if it had been content with drawing as dividends simply the profit allowed by law, it would have had on hand to-day every dollar that we now claim should be deducted for depreciation or loss in value of every kind and nature. It has made its own bed and is the author of its own misfortunes. To refuse to deduct the depreciation from present value is to pay this corporation twice, once in the award and once in the depreciation charges with which it lawfully and properly loaded its past water rates.

"Every public service corporation has the right to load its rates with an item for depreciation, present and prospective, that will pre-

vent any possible diminution of capital value from use in the public service, whether wear and tear physically or from loss of efficiency due to the fact that the territory served outgrows the capacity of the main features of its system. The Portland Water Company had that right. It exercised it. It collected the amount. It would to-day have been its full protection. It need not have lost a dollar in this award because of depreciation of any kind. It divided a part of the money and has the rest on hand. It has no one to blame for its folly but the greed of its stockholders and their want of business foresight. Having seen the city three times outgrow the capacity of the system, they should long since have prepared themselves for the emergency that faced them long before the Water District agitation began.

"Equally so of the serious loss in value due to the distribution of the Standish stock. When the stockholders of ten years ago lugged off the Standish stock, and left to the stockholders of to-day the burden of forever supplying the Standish Company with water without pay, they should have foreseen the present necessary and inevitable financial consequences. That the Portland Water Company of to-day must suffer heavily in value because of the greed of its stockholders of ten years ago is plain. The corporation has no one to blame for its present misfortune but itself. Five-sixths of the value of the Standish equity ought, in all equity and good conscience, to go to the Company that to-day and forever must carry the burden of the supply works needed to furnish the Standish Company with water. It goes to strangers. This is not the time to argue the point. I throw out the suggestion now simply because here, as well as in the matter of the depreciation losses, the loss in present value is the necessary consequence of the avarice and greed of the stockholders of the Company.

"The award should be fair to the Company, but it should be paid just compensation but once."

* * * * * *

Extract from Maximum Valuation Assignable to Property and Franchises.

"Continuing the assumption that the cost of reproduction represents the equivalent of the capital employed, the plant earning the maximum profit legally derivable from it, with a charter giving the right to earn from takers the full profit ordinarily derivable from all the service, with its present lawful income assured, with no depreciation, the quality of the service unattackable, the plant now fit to meet reasonable requirements in the present and future, efficient in every part, having kept pace with and reasonably anticipated municipal growth, with no acts of its own permanently depreciating its franchises, with no property not reasonably necessary to the service, with no structure unreasonably expensive, with the works prudently built,

what is the largest possible valuation that, with no new development, can be assigned to the property and franchises under the valuation rules of the Waterville and Brunswick cases?"

Extract from Ratio of Profit on Cost of Capital Employed.

* * * * * *

"We recur to the original proposition that whatever percentage or ratio of profit is selected to increase the return on capital employed beyond its annual cost or worth, necessarily just so much increases the value of the capital employed. And, inasmuch as this increment is due wholly to the maximum use of the franchises, the capital employed increased by the percentage selected as the ratio of profit gives the largest possible value assignable to the property and franchises (without new development), all premised upon the assumption that there are no depreciating factors. Deducting from this result the proper allowances for depreciating factors, whatever they may be, we have the present value of the property and franchises as they were in fact on January 1, 1908.

"It is not an easy matter to determine just what this ratio of profit ought to be. Upon its correct and fair determination rests the justice of this award, both to the public servant and to the public served.

"Were this a rating decree, this ratio of profit would determine the maximum rates to be paid. In that event the basic rate of interest to be allowed for cost of capital employed would be highly material.

"It is plain, as a simple principle of mathematics, that it is immaterial in a valuation decree what rate of interest is selected as the cost of capital, provided it be shown, as will be shown later, that, testing the rates, as charged, by any basic rate of interest and any ratio of profit that this Court would be likely to approve, the present return is legally excessive.

"The only law upon the point is the remark of the Court in the Brunswick case (p. 386) that the community may with reason prefer to pay rates which yield a return to the money of other people, higher than the event shows they could serve themselves for, rather than make the venture themselves and risk their own money to loss in an uncertain venture."

* * * * * *

"It may not be without value to make some study of public service corporations and their relations with capital.

"The data do not exist for studying the ratio of profit in other water companies in this State or elsewhere. No book is published giving the statistics of water companies. Water companies have hitherto been able to defeat all legislation tending to publicity by way of annual returns. Even if made, the usual practice of falsifying the cost of

construction, as in this case, would make the returns useless as evidence.

"A study of municipal water plants is futile. Their ratio of profit is often a minus quantity met by taxation. When a profit over cost is found, it is usually because the municipal policy is making the ratepayers pay for extensions out of earnings, or hastening the payment of bonds, or some other consideration to make the people believe that they are acquiring property without being taxed in fact.

"The only exhaustive and educating returns are those of railroads. They approach the standard of the water company nearer than any other public service corporation.

"The street railroad is yet too crude. Mechanically it is in its infancy. Its depreciation factor is as yet an unknown factor. Its fares are largely arbitrary and a matter of custom, not established in any sense on scientific principles.

"The electric light has, as yet, too many unsolved problems of maintenance and heavy unknown depreciation. Equally so, the telephone.

"The steam railroad, by long use and experience, by its closeness to the public, by partial public regulation, and by a growing system of scientific official returns, is somewhat analogous to the water company.

"Still the analogy is not perfect. The business risks of a railroad are great. The opportunities for loss through negligence constantly threaten earnings. There are many peculiar hazards and difficulties. It is dependent upon the general prosperity of the country in a large degree. Competition is usually a factor. It is far more subject to restrictive legislation. In short, it by no means presents the safety and security incident to an investment in a water plant in a prosperous city. And yet it approaches the safety and return and security of investment in water-works more nearly than any other public service corporation.

"A long and patient study of the official returns of the Maine Central Railroad covering several years, leads me to the conclusion that, applying to them the reasoning here used, its ratio of profit to capital cost is 1.26, and the Boston and Maine, 1.24. The Somerset Railway, an old road, 1.28, and the Bangor and Aroostook, a newer road carrying many risks, 1.40.*

"The expert for the Census Bureau, Professor Henry C. Adams, Statistician to the Interstate Commerce Commission, in 1904, computed the commercial value of the railways of the United States at $11 244 852 000. On this basis their full net return in 1906 was $6\frac{1}{10}$ per cent. The statistics for 1907 are not yet made up.

* Mr. Heath really means that the ratio of the cost plus profit increment to the cost is 1.26 to 1, etc., or, in other words, the profit increment of the Maine Central Railroad is 26%, Boston and Maine Railroad, 24%, Somerset Railroad, 28%, and Bangor and Aroostook Railroad, 40%.

"We respectfully submit that it is more than just to a water company, situated as this Company is, to fix its ratio of profit at 1.25. Assuming the cost of capital to be 5½ per cent., the maximum rate would yield 6⅞ per cent. on the capital employed as represented by the cost of reproduction." * * *

"We submit that capital will gladly enter the water-works field, whenever it can be assured by law that the full use of the franchises will enable it to receive from the public compensation for all original risks, full compensation for all capital used up in the service, an annual return upon the value of the property and franchises at the going rate of capital invested with like degree of safety, and that it may step out of the enterprise with such natural increment as may come to it, and with a profit equal to one-fourth of the original capital and its natural increment. It has earned in the meantime not only a return on the capital itself, measured by the going cost of such capital, but a like return on the natural and franchise increment. Such an opportunity and such remuneration is attractive to capital anywhere."

* * * * * *

"Renewing all these considerations, the fact that original risks have long since been paid for by the customers, that the days of hazard and difficulty were long since passed and paid for by customers, that the Company has once lawfully collected from its customers through depreciation allowances in the rates enough to make good all present depreciation, whether physical or functional, that the investment is now as safe, stable and assured as any form of private investment, that its prosperity is independent of panics and hard times, that the business is a practical monopoly, guarded by Courts and the Constitution of the United States, situate in a city with stable prosperity and serving a people respecters of equity and of law, with a system mechanically simple and comparatively free from loss through accident or negligence, independent in its earning power of the political hysteria of city government, in short, surrounded with the best attributes of safety and security, we submit that the ratio of profit of 1.25 is fair to the Company and that to allow more would be unfair to the public. * * *"

Application of Foregoing Principles in the Livermore Falls Water-Works Valuation.

As an illustration of the application of the foregoing principles, the Livermore Falls case has been selected from the three recent Maine cases cited, not on account of its magnitude, for the amount involved was small, but because it lends itself particularly well to the method of treatment used, and affords a good illustration, as all the essential facts were well established in the evidence submitted.

Data Relating to Community.—Town on Androscoggin River. Location due to fall in river and water-power development there. Power owned substantially by one corporation, International Paper Company, and all used except further down stream. A one-industry town, and that industry one which requires comparatively few employees. Considerable foreign population (mill hands), many living in frame tenement houses. Population less than 3 200, by count. Census statistics not applicable, as the village is in parts of two towns. Future growth doubtful, probably not large. Assessed valuation (figures not in the writer's hands at present).

Legal.—Date of franchise, 1889. Perpetual franchise. Exemption from town taxation for ten years, expiring a few months after date of taking. Works built in 1899. Date of taking, October 1st, 1907.

Physical Plant.—Gravity supply—maximum head approximately 125 ft., minimum 0 ft. Town on hillside, business district at lowest level, churches and many houses on a sort of middle bench, remaining residences on hillside above, many of them unable to get water on account of lack of available head or pressure upon the pipe system.

Source of Water Supply.—Moose Hill Pond. Drainage area 0.672 sq. mile. Water surface 0.142 sq. mile = 21.8 per cent. Storage per foot depth, 30 000 000 gal. = 45 000 000 gal. per sq. mile of drainage area (for depth of 3 ft., 125 000 000 gal., and 5-ft. depth, 200 000 000 gal. per sq. mile of drainage area). Quality admitted excellent. Quantity, safe daily yield 450 000 gal. (by agreement of engineers). Water consumption approximately 300 000 gal. per day, or 95 gal. per capita. 335 taps; 520± takers, substantially all on flat rate. No high-service system, though contemplated by company for several years, and legislative authority was obtained to issue securities therefor some years before taking.

No reservoir other than pond, 4 miles from town.

Pipe Distribution System.—Cast iron, chiefly. Ample in size for the most part, and generally efficient except for fire service. Service adequate for probable future needs, except for elimination of some small pipe and construction of high-service system.

Fire Service.—In business district, two "fair, ordinary fire streams" 185 gal. per min. 44 ft. high, 44 ft. horizontally. Middle bench or portion of town, "two feeble fire streams" 168 gal. per min. 36 ft. high, 38 ft. horizontal. Upper levels, no fire protection except from one fire steamer owned and maintained by town.

Operating Statistics. Financial Data.—

GROSS INCOME, OPERATION AND MAINTENANCE AND NET INCOME.

Year.	INCOME FROM:			Operating expenses, exclusive of interest and depreciation.	Net income.
	Water.	Service pipe, etc.	Total.		
1900*	$2 203.88	$49.86	$2 253.74	$342.42	$1 911.32
1901	3 359.13	129.15	3 488.28	344.01	3 144.27
1902	3 447.75	507.60	3 955.35	401.52	3 553.83
1903	4 246.26	216.81	4 463.07	661.86	3 801.21
1904	5 163.03	69.26	5 232.29	393.96	4 838.33
1905	7 020.88	157.73	7 178.61	733.71	6 444.90
1906	7 524.80	174.17	7 698.97	801.63	6 897.34
1907†	6 862.63	71.72	6 934.35	739.78	6 194.57

* Thirteen months from November 29th, 1899, to December 31st, 1900.
† Nine months.

The estimated rate of annual gross income as of date of taking was $9 364.50.

The operating expenses are very misleading, since no town taxes were paid by the company (under a ten-year exemption which was about to expire), and since the operators of the works were willing to forego salaries in return for dividends. The estimated reasonable annual operating expenses for current year, agreed to by the engineers for both parties, were:

Reasonable Annual Operating Expenses, Current Year.—

Wages (including administration).....		$600.00
(Charged by Company, $176.65.)		
Repairs, as charged by Company.....	164.52	
Expenses, average since 1901.....	245.07	
Taxes (Town tax on real estate, state and county tax on plant).....	290.10	
Town tax, 17 mills on, say, $60 000.....	1 020.00	
		$2 319.69
Annual depreciation (Metcalf).....		450.00*
Total.....		2 769.69

Depreciation (annual) $450.00 (Water Company's engineer estimated $345).

Resulting net annual income exclusive of interest charges $6 594.81, say, $6 600.

*Sawyer, $258.90 + $86.30 = $345.20.

Unit figures. Net earnings (including hydrant rentals but exclusive of depreciation and interest and dividends)—

$60.00 per million gallons.
19.70 " tap.
12.70 " taker.
2.06 " capita.

Average Annual Return to Builders of Plant.—

Amount paid in by stockholders, $1 000.

Dividends (1899-1907)	$10 000.00
Surplus on hand	3 965.36
Excess put in land chiefly for sale of lots and virtually a land speculation	11 700.00
Street work (grading) upon same	4 229.00
	$29 894.36
(Average per year, $3 857.)	
Add the interest paid to bondholders	25 320.41
	$55 214.77 *
Average per year	7 124.69
Percentage per year on investment of $65 477.61 plus $1 000	10.7%
Real estate purchase price (October, 1901)	$4 000.00
Estimate of market value by Company's officers	7 800.00
Estimate of market value by Town's witnesses	1 800.00
Structure value. Original cost by Company's books (admittedly approximate)	65 477.61
Reproduction cost by agreement of engineers, service pipes excluded (claimed by Company, but not admitted by town, as they were laid at cost of the consumer. Value, $1 845). Tapping fees collected, $1 806. (Both figures agreed to by engineers, subject to inclusion or exclusion by tribunal)	85 394.36
Supplies on hand	1 109.90

Depreciation.—By Company's expert—Annual $345
" Town's " " 450 = 0.527%

Total to date = $1 800. Estimate by Company's engineer.
" " " = 3 455 = 4.05%. Estimate by Town's engineer.

Cost of High Service.—Admitted necessary by Company; estimated only by Town's engineer, but not contested by Company as to fairness of estimate $17 300.00

*Of this amount, however, $3300 should be deducted as representing salaries not drawn

Additional annual expense involved in operation, maintenance and depreciation of high service	$600.00	
5% interest upon additional investment (no additional taxes figured here)	865.00	
		$1 465.00
Probable increase in revenue (estimated by Town's engineer)		986.00
Present net annual loss from operation of high service		479.00
Probable loss in value on this account (up to time when new business would carry the improvements)		8 000.00
Going Concern Value.—(By Town's engineer)		9 000.00

The details are not shown here as they are assumed not to be of any particular interest.

Value and Rating.—Worth of the Service to the Consumer.—Assume profit increment in this case to be 33⅓% and 6% as a fair rate of interest at the date of taking, October 1st, 1907, when boom prices prevailed. Then, as based upon reproduction cost as of date of taking, we should have:

Estimated reasonable operating expenses (as per p. 48)	$2 319.69
Estimated annual depreciation	450.00
6% interest upon reproduction cost ($85 394.36)	5 123.66
6% interest upon profit increment (33⅓% = $28 464.79)	1 707.88
Estimated reasonable annual gross income based upon reproduction cost plus 33⅓% profit increment	$9 601.23

The Company was not quite earning this. Therefore, on this basis, the value would not be reproduction cost ($85 394.36) plus one-third profit increment ($28 464.79) = total $113 859.15, but capitalized value of present income, assuming future growth to offset high-service needs, or

Rate of annual income at date of taking		$9 364.50
Deduct estimated operating expenses	$2 319.69	
Deduct estimated annual depreciation	450.00	2 769.69
Then estimated net annual income	=	$6 594.81
Capitalized at 6%	=	109 913.50

Same computation based upon actual first cost instead of reproduction cost.

Annual operating expenses	$2 319.60
Annual depreciation by Company's expert	345.00
6% interest upon original cost ($65 477.61)	3 928.66
6% interest upon profit increment (33⅓% = $21 825.87)	1 309.55
	$7 902.81

Actual gross income (rate) $9 364.50, therefore, on this basis, the rates are excessive, and, ignoring high-service needs, value would be:

Original cost	$65 477.61
Profit increment (one-third)	21 825.87
Total	$87 303.48

High service was imperatively needed. The Company was considering its need, and had taken preliminary steps toward securing it. The rates warranted it, and would have borne it. The cost of installation was estimated at $17 300, as has been shown. The allowable profit on this installation would have been $\frac{1}{3} \times \$17\,300 = \$5\,766.66$ on the assumed profit increment basis of one-third. The Company was entitled to a consideration of this profit as a future possibility or probability—not to its full value, as the work had not actually been done, but to a substantial portion of it.

On the other hand, this high service involves extra operating cost, depreciation and fixed charges estimated to amount to $479 per year in excess of anticipated increase in earnings. Therefore, on the reproduction cost basis, no increment in value would result. On the first-cost basis, however, the income would carry it and therefore an additional allowance might be made to the Company of say $5 000 profit (out of $5 766.66) making the total on the original cost basis approximately $87 303 + $5 000 = $92 303.

Summary of Valuation.—

On reproduction-cost basis	$109 913	
On original-cost basis		$92 303
Town's market valuation of real estate (by Company, $7 800)	1 800	1 800
Supplies on hand (agreed value)	1 110	1 110
Total	$112 823	$95 213
Deduct Town's estimate of depreciation to date	3 445	3 445
Net value on reproduction-cost basis.	$109 378	

Net value on original-cost basis	$91 768
Claims of water company	216 000
Award	117 698

As a matter of fact, Town's counsel claimed the following valuation:

Valuation of real estate (by Company, $7 800), by Town		$1 800
Supplies on hand		1 110
All other property		110 000
Gross amount		$112 910
Deduct: Depreciation to date by Town (by Company, $1 800)	$3 445	
Decrease due to fire service	8 000	
Item agreed upon by counsel	235	
		11 690
Net value (by Counsel for Town)		$101 220

Results to Town of Award of Assumed Value.—

Award, say		$101 220
Cost of fire service		17 300
Investment, exclusive of cost of litigation		$118 520
Annual income:		
Present income	$9 364.50	
New income	986.00	
		$10 350
Operation and interest:		
Operating expenses	$2 769.69	
Operating high service	600.00	
Trustees' salaries	300.00	
Interest, 5% on $118 520	5 926.00	
Sinking fund, 1%	1 185.19	
		$10 781

Any increase of the award, above $101 219.90, would require an increase of water rates.

Unfortunately, the writer heard but a fragment of the final argument of Counsel for the Water Company and, therefore, is unable to give all the Water Company's figures (except Counsel's valuation of $216 000), but has asked its expert, Walter H. Sawyer, Assoc. M. Am. Soc. C. E., kindly to submit in discussion any essential data which may have been omitted, and to correct any inadvertent errors in the statement of the data upon this case made in this paper.

Some Significant Rulings Upon the Admissibility of Evidence by the Appraisers in the Portland (Maine) Water-Works Valuation Case.

In the course of the trial in the Portland water-works valuation suit, some important questions of general interest in water-works valuation were ruled upon by the tribunal, and in view, not only of the magnitude of the case—which covered the valuation of the plants of the Portland Water Company, the Standish Water and Supply Company, the Gorham Water Company, the Foreside Water Company, and the Presumpscot Water Power Company, and amounted to nearly $4 000 000—but also of the excellence of this tribunal (which was made up of Judge Albert R. Savage, of the Supreme Court of Maine, the writer of the Waterville and Brunswick opinions and Chairman of this Board of Appraisers; Judge Frederick A. Powers, recently retired from the Supreme Bench of Maine, who had previously sat as Chairman in the Waterville and in the Livermore Falls cases, and had participated in the Waterville and Brunswick decisions; and United States Marshal Henry W. Mayo, who had himself previously served upon water-works appraisal boards), it may be of interest to quote the more important of these rulings, which may be assumed to be indicative at least of the probable attitude of the Supreme Court of Maine upon the points in question.

These rulings covered the question of admissibility of evidence upon the following issues:

1.—Expert testimony on "going concern" value, "franchise" value, and total value of works. Excluded, except upon purely technical questions involved.

2.—Need and cost of reinforcement of distribution pipe system. Admitted.

3.—Selling prices of water company stock as tending to show value. Excluded.

4.—Depreciation, as based upon or measured by the substitution of another equally efficient or different structure to do the work of the existing structure. Excluded, except as bearing upon relative efficiency of the plant.

The trials of the last three Maine water-works valuation suits, which were all conducted on behalf of the several municipalities by the Hon. Herbert M. Heath, of Augusta, were unique in American annals of

such cases, in that Mr. Heath argued successfully against the admission of any testimony upon the total value of the property of the water company by the experts or engineers, holding that in valuing the property as a whole the expert was usurping the functions of the tribunal; that expert testimony was admissible only in so far as it dealt with facts or matters of opinion beyond the ability of the layman to grasp without expert assistance; and that valuation implied a thorough knowledge of value standards, a knowledge of the law as well as of engineering principles or theories, since valuation was a mixed question of fact, judgment, and the law, and therefore must be made always with a full knowledge of the law upon such cases. The appraisers in all these cases (Kittery, Livermore Falls, and Portland) sustained this contention, as appears in the first ruling, quoted later. These rulings are the only examples of such a ruling in water-works valuation in America that have thus far come to the attention of the writer. The experts only testified to engineering facts, principles, and costs, and not to property values or the elements thereof. In each case, however, the engineers assisted counsel in the preparation of the necessary tables and data upon valuation, which thus went into the arguments, instead of being presented in testimony. The plan here followed appears to have some advantages, and it seems likely to be tried elsewhere unless exception should be taken to the ruling, be carried up to the full bench, and there be upset on the broad ground of expediency. Abstracts of the rulings follow:

Ruling on Admissibility of Expert Testimony on Going Concern, Franchise Value, and Total Value of Works.

"The Appraisers have taken into consideration the question that has been argued, and I have now to state the result of their conference. Disregarding the precise form of the question which was asked originally, and which we perhaps have forgotten, but taking into consideration the real question which is presented, and which has been argued by counsel, it is, as we understand it, in effect whether the characteristic of going concern values in a case like this can be properly proven by expert testimony. It is not a question whether evidence tending to show a going concern value is material. I do not apprehend that either counsel would take that position; because what is called going concern value is a characteristic of structure, and, if there is any such characteristic, it must be shown by evidence. The only question here is whether the evidence, tendered legitimately, is admissible for

that purpose. It may be regarded as presumptuous for a tribunal made up as we are to undertake to illuminate the opinion of the court in the cases in this state which have grown out of proceedings of this character. However, we have—those of us who sat in those cases—gone over the language of those opinions. Mr. Mayo agrees with us that there is nothing in the later case which detracts or modifies anything that was decided in the former case. In the former case the court was asked to say that, in determining the amount to be added to structure value in consideration of the fact that the system is a going concern, 'the Appraisers should consider, among other things, the present efficiency of said system, the length of time necessary to construct the same *de novo,* the time and cost needed, after construction, to develop such new system to the level of the present one in respect to business and income, and the added net incomes and profits, if any, which, by its acquirement as such going concern, would accrue to a purchaser during the time required for such new construction, and for such development of business and income.' And the court said, 'We think this instruction should be given.' The present efficiency of the system, the length of time necessary to construct the same *de novo,* and the time and cost needed, are all matters which affect the characteristic or element, whichever way you may choose to phrase it, of the going concern feature of an existing business.

"Now in the Brunswick case,—and I will say right here with regard to the Waterville case, what will also apply to the Brunswick case, that, although the court used the language that the questions before the court, which are comprehensive in scope and minute in detail, in effect relate to the admissibility of evidence, yet they must be decided before the court knows or can know what specific evidence will be offered or relied upon or to what conditions the evidence will be applicable. In such cases it is evident that the answers must be general in character. While it is true that the answers to all these questions do affect the admissibility of evidence, really in effect they laid down rules which made evidence admissible or inadmissible according as it came on one side or the other of the rule. I apprehend that that was substantially what was meant by the court in that expression: 'Specific forms of proof were not under consideration.' How the various elements or characteristics should be proved was not discussed nor decided; and that applies as well to the Brunswick case.

"In the Brunswick case the questions are not printed in full as they were in the Waterville case, but they are incorporated in the opinion, and the first question was, as stated in the opinion, 'We are asked to say that "in applying the rule that the basis of all calculation as to the reasonableness of rates to be charged by a public service corporation is the fair value of the property used by it for the convenience of

the public, franchise values are to be wholly disregarded, and the element of going concern value is to be considered only as involved in the structure value; that property value, in this connection, means structure value only."' Then it was that the court thought it was expedient, and perhaps necessary, to lay down some of the principles which affect property of this character. It said that there were three things to be thought of, to be considered, and that none of them could be excluded. They must all be considered. In the end there was a single, final, net result, that none of them could be eliminated from consideration, neither the structure as such, nor the fact that it was in use, nor the fact that there was the right to continue to use it in the place and situation where it was; so that we were unable to give the instruction which we were asked to give for the reasons stated in that opinion. Therefore we feel that we are safe in saying that the two cases are not inconsistent, and that neither is a modification of the other. They discussed propositions from somewhat different standpoints; that is, the questions suggested different ways of approaching them.

"Now we come to the question whether this added element, this enhancement, so far as relates to the going concern values—and I suppose the same ruling applies to franchise values—can be separated out and made the subject of opinion evidence, expert testimony. The question which was asked assumed that a certain number of dollars per annum was a reasonable income. Of course, that assumption is based upon the results of the application of certain rules of law; but there are still other questions of law which, in our judgment, would affect or should affect an answer to a question of that kind, concerning which we have no right to suppose that the witness is qualified to speak. It seems to us that the question of going concern value is material; that it may be shown that in this case, so far as the Company's side is concerned at least, all the facts which affect going concern value are already in the case; and that for a witness, no matter what his experience or wisdom, to undertake now to derive conclusions from that evidence or state them as conclusions, would be merely stating what appears to him to be the effect of the evidence already introduced in the case. That, as we conceive it, is not the proper scope of opinion evidence. It seems to us that the question is one of argument, one of reasoning conclusions to be derived from the facts in the case. It may be that, in the final consideration of the case, all of the reasons which Mr. Wheeler thinks support his conclusion would be properly presented to us as arguments from the facts proven; that is to say, take the whole case, take the history of the Company, take the number of water takers, take the income—take all of these separate and individual facts which have been declared here one by one, and then how much weight or effect should

be given to these facts as affecting the value of the structure because it is a going concern is a matter of argument, of reasoning, and not a matter of opinion evidence; and in that light we exclude the question asked, and shall exclude questions of a similar character.

"It may be summarized in this way: It is not competent for the witness to tell us what his conclusions are from the evidence, but we are the ones to draw our own conclusions after argument."

Ruling upon the Admissibility of Evidence on Need and Cost of Reinforcement of Distribution Pipe System.

"The line which marks the division between testimony admissible with reference to so-called improvements, we think, is pretty fairly well established. The Water District is to take this plant. Comparisons between this and other plants of different construction, differently situated, are not admissible. The District is to take this plant, take it with all its merits and with all its demerits, all its efficiency and inefficiency, if the same is proved. Now if this system is inefficient in any particular, of course, that is a subject of proof which must be received and weighed by the Appraisers, and in some way the extent of the inefficiency finally to be measured in dollars and cents must be ascertained by proof, and not be left to the Appraisers to guess at.

"Now the questions concerning which the discussion has arisen relate to the efficiency of the fire service within the city of Portland. As we understand it, the Portland Water Campany is now, has been, under certain charter and contractual obligations with reference to the maintenance of a reasonably efficient fire service, that is, to supply water for such a service. That means to supply, not including hydrants or the location of them, but the other means of conveying the water to the various places where it may be needful for the purpose of extinguishing fire. The District takes the plant subject to those obligations. Now it seems to us that if it be true that the system is inefficient, does not come up to the standard which the charter and contract require, we must in some way know wherein it is inefficient, and how much it is inefficient—not only by having a general statement as to the character of inefficiency, what it fails to do, but what is necessary to make it do what the contract and charter require it to do. That is not figuring on another system, on a new system—it is merely getting at in some way the point wherein this system is said to be lacking. The witness upon the stand has said that in some respects he regards the feature of fire protection as inefficient, and he has stated his standard of efficiency, what he understands and means by the term efficient. Now are we to go along and be satisfied with that unless we know what it lacks, what makes it inefficient? That seems to us to involve further the question of the amount of

inefficiency, that is, what it would take to make it efficient, because we cannot measure the inefficiency by guesswork, and in a general sense we think it is true that, when a thing is inefficient, the lessened value by reason of its inefficiency is what it would cost to make it efficient. Suppose, for instance, there were in this case a question about the purity of the water itself, would it not be competent to show how much it would cost us to put in a filtering plant to make it efficient? Would it be proper to show that a filtering plant would do it, and for that reason was necessary to do it, and then how much it would cost? Supposing—that may not be true of this case—that there was a lack of reservoir supply, and that, in order to enable the Company now or the District hereafter to perform its charter and contractual duties, it is necessary to have a larger or a higher reservoir. That is very easy to state, but how are the Appraisers going to know what deduction to make for inefficiency unless they know what it costs to make it? It is this system, not another one, not a new one, but this system brought up to efficiency. We cannot tell without evidence whether the proposed inefficiency may be remedied by putting in a couple of hundred feet of large pipe at a minimum expense or whether it might cost thousands and thousands of dollars; we do not know anything about it, and we cannot guess at it. We think then that it is competent for the District to show the particulars wherein the present system is inefficient in detail, whether it be the pipe or the outlet from the reservoirs, or wherein it fails to come up to the standard of efficiency. Whether the standard of the witness is too broad is another question. But whether this system comes up to the standard which he as an expert has testified to, we think it is competent for him to say. We must know from evidence something about how much it will cost to put it where it ought to be, if it lacks now in efficiency; and there we think is the line between what is admissible and what is not. With that in mind we admit the question."

* * * * * *

"Excuse me, Mr. Baker, but there is one thing further I intended to say that, while that is admissible, there may be some compensating advantages on the other side which of course the Commission will have to take into account, for instance, for any improvement of the general water system, the Company is entitled to the benefit of so much compensation as is properly derivable from it."

* * * * * *

"Of course the testimony is admitted from the standard which the witness himself sets. If the court thinks that is an extravagant standard, it will have to be taken into account."

Ruling upon the Admissibility of Evidence upon Selling Prices of Water Company Stock as Tending to Show Value.

"The question was argued several days ago, and afterwards we gave the matter not only careful examination in conference among our-

selves, but we also carefully examined the authorities which were cited and relied upon. Perhaps it might be sufficient to merely state the conclusion at which we arrived; but, in this case all through we have thought it best to adopt a policy in deciding questions of importance to state the reasons of our rulings. This is only fair to the parties, inasmuch as it is possible that it may not be easy to have our rulings reviewed. Accordingly I will attempt briefly to state the reasons which lead us to the conclusion which we shall announce.

"Of course, evidence of sales of a thing which is under consideration, when the value of that thing is a material issue, is admissible, although ordinarily these are *res inter alios,* admissible because they are the acts of parties having opposing interests, and looking at the value of the thing from different standpoints under circumstances calculated to produce as nearly a correct result in judgment as any human conditions can; and they are supposed to be the result of the judgment of persons who know, or who assume to know, something about the conditions and quality of the thing sold. If they did not know anything about the essential conditions which entered into the value, the testimony would not be significant or of any importance. Now that is the rule as we understand it or the reasons for it in general. Applying that to this case, or, to lead up to it, first speaking of the matter of authority. The authorities cited by the learned counsel for the Companies seem to divide themselves into three classes. In the first place, as I speak of them, there are a large number of cases where, in tax proceedings or in determining the validity of tax proceedings, the question of franchise valuations was under consideration by the courts, and where the State, seeking to tax the entire value of a corporation, finding that there was a value represented by the entire market value of the stock over and above the value of the plant, the physical value, assessed the difference as being a fair representative of the franchise values. We think that those cases differ very materially from the question which is now presented before us. Of course the State will assess, and should assess, such franchises as the company claims to own, and to be in profitable use of. It will not inquire into the question whether those franchises are used improperly or whether more income is derived from them than should be derived from them under proper tariff rates or prices. If the Company is using them and receiving certain income from them, we apprehend that the State will take the Company's view of the uses which properly may be made when it attempts to assess franchise values. Of course this is a different question from what we have now, where we have to go back of the Company's view of it to get at the real legal rates of income which may be chargeable.

"Then there is another class of cases like the Pennsylvania cases where the court, in discussing values of public service corporations, did state the rule as embracing in evidence the value of the capital

stock, the market sales of capital stock as being evidence, not conclusive, but as having some bearing upon the propositions as to the value of the thing itself. We notice that those cases were cases heard and determined, as I remember it, at a date earlier, a time earlier than what may be called the new light on public service values, when the matter had not been so thoroughly studied and differentiated as it has been in more recent years. Those cases make no distinction whatever between public service corporations and other kinds of corporations, nor do they recognize, so far as I remember, the peculiar rules which are now held to attach to the values of public service plants and franchises; and, for that reason, we do not regard them as authoritative—not in this state anyway. But any decision in those days, before the theories were exploited as they have been now, will have to be taken with some considerable question.

"The last class of cases, or the class which embodies perhaps the single case of Smith *v.* Ames, where Judge Brewer did say that in a case involving the unreasonableness of rates charged, that is, whether the rates were confiscatory or not, that the value of the stock was an element to be considered. What Judge Brewer might say about that now in view of more thought, later thought upon the subject, of course no one knows. It was not a question arising on the admissibility of evidence, so that the precise point was sharply presented and argued, but stated by him discursively in his opinion in that case.

"Upon the whole we are of the opinion that we are not concluded by any of the authorities which have been cited; also that we ought not to feel embarrassed in discussing them or considering them in the light of reason.

"When we come to the reason of it, it seems to be something like this: It may be true that if we were to-day valuing an ordinary corporation like a manufacturing corporation, a mercantile corporation, any corporation not engaged in the public service, public utility corporation, it might be that one way of measuring its value over and above the physical value would be to get at the value of its stock sold in the market. The people who bought and sold such stock may be fairly supposed to know what they are buying and selling, and what the rights, what the limitations upon such corporations are. There is no limitation to the amount of money which such corporation is entitled to earn if it can get it; no limitation outside of the charter as to the lines of business in which men engage. All the things which seem to establish the value of such stock may be fairly known, may be fairly presumed to be in the consideration of the men who bought and who sold. But when you come to the matter of a public service corporation, we are met at the very outset with this great difference; that the rights of the corporation to earn money are limited, that is to say, to earn money, to make a charge to its customers. They are limited

by rules of law which are not easy, always, of application, they are limited by rules of law which we think are not and cannot be deemed to be within the knowledge and contemplation of investors in its stock. It would be rather a far reach to say that investors even contemplated the physical plant, the most of which is out of sight. Of course this is a matter which would rather go to the weight of the evidence. There are elements in it of law, the application of legal principles which in our judgment remove it from the rule which might perhaps properly be applied to a business corporation; and it is because of this unknown and unknowable element of the legal application of rules to the rate question that we think the testimony is beyond the limit of admissibility. The investor in a property of this kind invests not upon what he sees of the plant, but upon its financial results, always upon the financial results which have already been attained, the dividends now being earned and declared, the reasonable prospect of business in the future; but that is and must be without regard to the application of legal rules of limitation which we think are beyond, and must be deemed to be beyond, the understanding of the investor, who buys and sells the stock; and for these reasons, after very careful thought and quite an extensive examination, we have all come to the conclusion that the testimony is not admissible."

Ruling on the Admissibility of Evidence on Depreciation Based on the Substitution of Another Equally Efficient but Different Structure to do the Work of the Existing Structure.

"The Appraisers have considered the question submitted, not only at this time, but each of us has given some consideration to the subject since it first arose. The solution of the problem really involves several considerations in the valuing of this plant which is to be taken. One of the elements—and it is only one of the elements—is the present value of the structure, as a structure. That is not all. There are many other considerations which apply to the value of the plant to the Company—its value to them. Among those considerations is the question of efficiency. If the plant is efficient and it can do now all that it is legally and properly bound to do, why, that is one thing. If it cannot do now all that it properly should be required to do, then there arises the element of inefficiency, and if it is inefficient, then it is worth less to the Company to hold and to keep than it would be if it was efficient.

"Now it is in our judgment entirely proper for the taking Company, in introducing evidence so that we can fix the present value, and take into account efficiency, to show wherein it is inefficient, and what it would cost to make it reasonably efficient. That affects the present value of the plant; and we must assume as to the question, as we do assume, that as to efficiency, from that standpoint, that the question

of admissibility must be considered. They say it is inefficient and they have a right to prove it if they can.

"Now, Mr. Hazen has pointed out as an engineer the features of inefficiency. He has been permitted to show wherein and how the present system may be made efficient to-day or on the first day of January, the time when the taking took place; and the cost of making it efficient on that day—not taking properly the cost of making it efficient for some future demands and future growth, but efficient as of the first day of January. Now it may be that, in making it efficient on that day to meet present demands, that the results—the beneficial and pecuniary results may be very largely in excess of the cost of making the enlargement of improvement, the enlargement and improvement limited to making it efficient on the first day of January—not in regard to future demands.

"Now, Mr. Hazen says, as we understand it, that in going over this problem and studying it—at least so far as one of the elements that enter into this taking is concerned—he has considered the business proposition, the economical proposition from the standpoint of whoever may be faced with the practical problem. He says that, while a certain arrangement or certain things may to-day be such that practical business men would not do it that way because it involves so much waste and loss in view of future demands that may be made, so he has taken into account, as he says, the business problem. He assumes that this work should be done practically now—that is covering the period of two years to do it, but making five years to cover contingencies to make it practical; and upon that assumption, or business assumption, he has introduced what seems to us to be a new system so far as the supply part of the property is concerned, and that after five years the whole system would become salvage, what is left of it, and that there will be a new pipe or should be for the business standpoint of very much larger capacity than the present pipe, in a new location and under new conditions. And taking that as one of his elements he reasons out upon his statement what the results would be from an engineering and a pecuniary standpoint—economical standpoint.

"Now, of course, Mr. Hazen is entitled to give his conclusions as to efficiency and his reasons for them. Whether the reasons are sound or fallacious does not affect their admissibility. If they are fallacious they can probably be shown to be so, and if they are not they would stand. But whether his theory involves elements not proper to be considered in arriving at the result is a question to be considered respecting its admissibility, and we think that the introducing of what is practically a new system of supply goes beyond the limit, because, as he says, at the end of five years it would be a new and larger supply system, which opens a door into the future to such an extent that the testimony in our judgment is not only improper but goes beyond the line of legal admissibility.

"The record, as it comes from the stenographer's hands, does not show the precise question which was involved, because the witness was asked to turn to his table and that does not appear in the record, but we have the table as passed to us in the examination and assume he was to explain his views upon this table as to the mathematical result at which he had arrived from his system of computation; and that, as presented, we exclude."

Effort to Eliminate, in Water-Works Valuation, the Value of Franchise and Other Rights Acquired by Legislative Grant.

With the growing recognition of the rights of the public, and the obligations, as well as the rights of public service corporations, has come the endeavor on the part of the public to retain for itself, in granting authority to operate quasi-municipal corporations, any values that may develop directly from these grants.

Thus Massachusetts has sought to eliminate the element of franchise value in water-works valuation by express provision in the Charter or Incorporation Act of the Companies, covering this point; hence in the Haverhill, Newburyport, and Gloucester cases (as in the Kansas City case), franchise considerations were eliminated and the works were appraised upon the basis of their value to the purchasers rather than to the sellers, as is provided for in the Maine rulings.

A somewhat similar situation is found in England, as outlined in the report of the London County Council upon the "Water Supply of London, and a Bibliography of the Principal Reports and Papers on the Subject, Together with a Special Report by the Comptroller of the Council on the Financial Aspects of the Purchase."*

English Precedent for Restricting the Valuation of the Franchise and Other Rights Acquired by Grant.

London's water supply dates back to the 13th century, when the Corporation of the City of London obtained leave to construct conduits for the purpose of bringing water from Tyburn to the City "for the profit of the City, and good of the whole realm thither repairing; to wit, for the poor to drink, and the rich to dress their meat." The system was more or less extended until, in 1580, the first rights were granted for supplying water to the public through private undertaking. From that time rights were granted at long intervals of time to

*Printed for the London County Council by P. S. King & Son, in June, 1905.

additional water companies, until there were eight or perhaps more water companies supplying the City of London in the early part of the last century.

The service rendered by these companies proved inadequate, as was shown by the comment of Sir George Grey, in introducing his Parliamentary Bill upon this subject in 1851, that "competition could not be safely trusted to secure an adequate supply of good and wholesome water which was essential to the health and comfort of the inhabitants of the metropolis," and led to growing discontent on the part of the public. This resulted in the formation of a series of Committees of Parliament and County Council for the consideration of the public control of the water supply, extending from 1821 to 1902, in which latter year was passed the "Metropolis Water Act," "for the purpose of acquiring by purchase and of managing and carrying on the undertakings," of the water companies, and "generally for the purpose of supplying water" within an area differing in some respects from the limits of actual and possible supply of the companies.

As far back as 1891, the London County Council reported, among other things:

"2. * * * That for certain purposes at least it would be desirable to acquire the undertakings of the existing companies if the same could be obtained on fair and reasonable terms.

"3. That the Council is of opinion that the price to be given for the undertaking of any company should depend, not merely on past dividends or on Stock Exchange values, but upon the true value of the undertaking, having regard to its legal position and liabilities; to the condition of the property; and to its ability to supply future wants.

"4. That, in order to arrive at a satisfactory conclusion on this last question, it is essential, before any terms of purchase can be considered, that the liabilities to capital expenditure for new or supplementary sources of supply in the immediate future should be authoritatively ascertained."

The works were finally taken on a basis of their fair and reasonable value.

In the course of this long-protracted struggle between the public and the water companies, the restrictions under which Parliamentary grants were made to the water companies, permitting them to extend their facilities and service, became more and more drastic from the companies' point of view, and protected the rights of the city more

and more carefully from the public point of view. Thus in the Act of 1847, it was provided that:

"The profits of the undertaking to be divided among the undertakers in any year shall not exceed the prescribed rate, or where no rate is prescribed they shall not exceed the rate of ten pounds in the hundred by the year on the paid-up capital in the undertaking, which in such case shall be deemed the prescribed rate, unless a larger dividend be at any time necessary to make up the deficiency of any previous dividend which shall have fallen short of the said yearly rate."

In 1878 Parliament introduced:

"Into the Grand Junction Company's Act of that year, authorizing the raising of fresh capital, what are known as the Auction Clauses, which were designed to secure the economical raising of capital by compelling the companies to offer the stock for sale by public auction or tender."

In 1886 was passed the Sinking Fund Clause:

"The object of which was to secure for the public, by means of transfer to a Trust Fund, some share in the increasing profits of the undertakings.

"The effect of the section was that, after three years from the issue of any debenture stock under the Acts, the companies had to pay each year to the Chamberlain of the City of London the difference between the profits earned by the stock as part of the entire capital of the companies and the interest actually paid to the holders of the stock plus 1 per cent., which was allowed to the companies for 'management.'

"This allowance of 1 per cent. was proposed by the City Corporation as a sort of margin to the companies for managing the business. As a matter of fact, inasmuch as all the expenses of management were necessarily charged against profits before ascertaining the proportion of profits attributable to the new debenture stock, the 1 per cent. was really a bonus or present to the companies concerned."

In some of the later Acts, as in the Staines Reservoir Act of 1896, and the Kent Co. Act of 1902, a Sterlization Section was inserted as follows:

"Nothing in this Act shall authorize the company to bring into account or to make any claim in respect of any advantages conferred on them by or resulting from the passing of this Act. Provided that in the event of such purchase the company may bring into account the actual amount of any capital expenditure made by them in exercise of the powers of this Act.*

* Extract from Section 20, Kent Co. Act of 1902.

"The sinking fund and sterilization clauses were designed to secure in part the same object, viz., the non-enhancement of the value of a company's undertaking in the event of purchase by reason of the further advantages given to the company by the special Act, but they differed in important respects as regards the manner and extent of their operation. The sinking fund attached only to capital powers authorized and directly affected the profits of the company by appropriating annually in perpetuity a portion of such profits for the benefit of the public. The sterilization clause, on the other hand, was directed solely to the contingency of purchase, and its operation was limited to a particular period of years; it was in general terms and could be applied both in the direction of reducing the company's future profits for the purpose of purchase, and as affecting the number of years' purchase, because its effect was to deprive the company of any advantages conferred by, or resulting from, the passing of the special Act.

"The importance of this legislation can hardly be over-rated, but the companies were purchased before its full effect had been felt."

All as stated by the Comptroller of the London County Council in his report.

The valuation of the London companies appears to have been based upon a consideration of:

1.—The dividend being earned by them upon the capital stock of the company which is restricted rigidly to actual cash investment; allowance being made for a 10% dividend from the time of incorporation of the company, provided the income of the company justified this return.

2.—The probable continuity of and growth in future income.

3.—The character of the plant and of the service furnished and the probable needs of the future.

4.—The effect of the sinking fund, sterilization, and other similar clauses under which the companies were operating.

5.—A 1½% allowance for cost of reinvestment and other costs.

As stated by the Comptroller, the company's works were valued upon a basis of their value to the vendor, rather than to the purchaser; upon the "perpetual existence of the companies, and apparently upon the adoption of an average of the past ten years as a starting point for their valuation."

The Comptroller further observes that he doubts "whether sufficient weight had been attached in the recent arbitrations to the large expenditure on capital account which will be required at no distant date."

TABLE 4.—Some Recent Awards in New England in Water-Works Valuation Cases.

Date of taking.	Name.	Year of original construction.	Population.	Estimated actual cost.	Reproduction cost. Approximate.	Depreciation to date.	Approximate net annual income, exclusive of depreciation and interest charges.	Award.	Award per capita.	Ratio of award to reproduction cost.	Ratio of net annual Income to award without allowance for depreciation. %
June 12, 1887	Braintree, Mass.	.....	4 300 (1)	.....	.....	.....	$10 750 (2)	$159 610.44	$37.12	.....	6.7
Oct., 1895	Gloucester, Mass.	.....	28 211	.....	.....	.....	.....	600 500.00	21.29	.....	....
1898	Fulton and Oswego Falls, N. Y.	.....	.....	.....	.....	.....	11 340	172 500.00	.....	.....	6.6
1901	Newmarket, N. H.	.....	1 800	.....	.....	.....	5 100	83 000.00	46.11	.....	6.2
1902	Dover and Foxcroft, Me.	.....	3 600 (1)	.....	.....	.....	7 057 (3) 7 500 (4)	135 659.31	37.70	.....	5.2 5.5
1903	Gardner, Mass.	.....	11 700 (1)	.....	$165 000.00 (5)	....	13 700 (6) 20 000	274 000.00	23.42	1.66	5.0 7.3
Jnly 1, 1903	Gardiner, Me.	.....	7 380 (1)	.....	132 000.00 (7)	$35 854 (7)	15 556	245 000.00	33.20	1.85	6.4
July, 1903	Waterville, Me.	1887	17 600	$250 000	368 546.00 (8) 288 776.00 (7)	32 400 61 800	32 700 (9) 34 580	503 475.37	28.58	1.37 1.74	6.5 6.9
Jan. 1, 1904	Brunswick, Me.	.....	6 930	.....	130 455(24) (7)	18 529 (7)	15 000 (25)	196 162.09	28.31	1.24 (24)	7.7
1904	Augusta, Me.	.....	12 100 (1)	300 000	.....	.....	31 000	427 135.20	35.29	.....	7.3
Jan. 1, 1905	Athol, Mass.	1877 (?)	7 196	.....	206 386.00	39 253 (7)	17 000	316 500.00	43.99	1.53	5.4
1905	Amesbury, Mass	.....	8 840	.....	205 573.00	46 521	13 000	265 000.00	29.98	1.29	4.9
Dec., 1906	No. Conway, N. H.	1884	1 700 (12)	.....	35 300.00 (13)	8 100 (14)	3 700	62 000.00	36.46	1.76	6.0
1906	Ithaca, N. Y.	1872	18 000 (15)	.....	551 575.00 (16) 322 793.00 (17)	.....	40 750	658 000.00	36.56	1.19 2.04	6.2
Jan. 1, 1907	Derry, N. H.	1891	4 500	.....	80 878.06	12 750	7 399	125 500.00	27.89	1.55	5.9
July, 1907	Kittery, Me.	1902	3 000 (18)	81 000	102 510.25	2 200	10 786 (19)	163 869.00	54.70 (18)	1.60	6.6
Oct., 1907	Livermore Falls, Me.	1899	3 142	66 000	85 394.36	3 455 (20) 1 800	9 364	117 698.00	37.46	1.38	8.0
Jan. 1, 1908	Portland, Me.:										
	Portland Water Co.	1868 *et seq.*	45 600	1 425 500	1 525 476.00 (21) 1 685 696.00 (22)	656 694 (23) 84 609 (8)	..... 147 055	.....	.....	.....	.....
	Gorham Water Co.	1895	2 500	.....	67 000.00 (21) 71 960.00 (22)	5 856 (23) 4 504 (8)	..... 2 291	2 539 235.00	51.20	1.53	5.9
	Foreside Water Co.	1906	1 500	58 300	70 400.00 (21) 71 920.00 (22)	649 (22) 212 (8)	 0	.....	.....	.....	.....
	Standish Water and Constr. Co.	1886 and earlier.	28 600	.....	931 500.00 (21) 1 024 120.00 (22)	233 394 (23) 35 014 (8)	64 200	1 313 798.00	45.94	1.41	4.9
	Average of column								$36.40*	1.54	†6.2
	Average based upon totals								37.52*	1.50	†5.9

* Excluding Fulton and Oswego Falls. † Excluding Gloucester.

It is also interesting to note that, as in the recent Maine cases, "the Court ruled that the question of the value of the undertaking was a matter for the Court, and his evidence (the witness') was therefore limited to facts concerning the condition of the Company's works and plant."

It is impossible, within the limits of this paper, to discuss in detail the awards in the London cases, but those particularly interested in this subject will find the report of the London County Council, referred to, well worth perusal.

Some Recent Awards in New England, in Water-Works Valuation Cases.

Table 4, though more or less fragmentary, may be of casual interest to the reader, especially if he is familiar with the works. Without a fair knowledge of local conditions, it is not safe to generalize from figures of this kind. Particular attention is called to the fact that no deduction has been made from the net annual income to cover depreciation or interest upon fixed charges, and similarly in determining the ratio of net income to award, this ratio is determined from the approximate net annual income exclusive of depreciation and interest charges as shown.

Notes to Table 4.—

(1) Estimated from Census.
(2) Charles F. Parks' estimate of future income, including estimated hydrant rental.
(3) Normal for 1902, estimate of expert for company.
(4) Anticipated for 1903, estimate of expert for company.
(5) Finding of Commission after deducting depreciation on value of physical plant, exclusive of water rights, street franchises, and going concern value.
(6) Finding of Commission on fair net or divisible income.
(7) F. C. Coffin, expert for town.
(8) William Wheeler, expert for company.
(9) Estimated by Water District Engineers.
(12) Exclusive of large summer population.
(13) Agreed reproduction cost exclusive of engineering and contingencies, $31 380. Amount given includes 12½ per cent.

(14) Town experts' estimate.
(15) Exclusive of 3 000 at University.
(16) Average of company's experts, after deducting depreciation.
(17) Average of city's experts, after deducting depreciation.
(18) Bulk of water used at Navy Yard for manufacturing.
(19) $10 346, less depreciation.
(20) Approximate.
(21) Exclusive of service pipes, hydrants, and drinking fountains.
*(22) Inclusive of service pipes, hydrants, and drinking fountains.
(23) Exclusive of services, etc., Water District experts' estimates.
(24) Agreed reproduction cost by engineers, $158 389.40.
(25) Average net revenue, 5½ years, $14 434.40.

Water-Works Valuation.

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* Ownership at issue, and probably vested in the water consumers.

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Conclusion.

It seems unnecessary to attempt a recapitulation of the matters discussed herein, as the length of this paper has far exceeded intended limits, and as only comparatively few directly interested in water-works valuation and fair-rates cases will be likely to scan these lines. The paper was prompted by the desire to submit, for discussion by members of this Society, the method outlined herein of applying, in water-works valuation, the vital principle or gauge of fair rates—"the-worth-of-the-service-to-the-consumer," so admirably laid down by Judge Savage in the Brunswick decision—a decision destined to be much quoted, and to exercise a large influence in water-works valuation and rating cases in the future.

It is not suggested that the method discussed and illustrated herein is the only correct method, or the final criterion of value, or that it is the interpretation which the Supreme Court of Maine would put upon its own ruling. It furnishes, however, another standard for water-works valuation and for the determination of fair rates—perhaps a more tangible and rational one than some that have been used in the past.

As applied to works which have been seriously over-capitalized to cover up excessive earnings, it will bear heavily; to capital actually and prudently invested in the property, it will afford ample protection.

To old and outgrown works which, not content with dividing the real earnings of the company—and failing to recognize and provide for the inevitable depreciation resulting from lapse of time, long service, and other conditions—have actually divided up the plant in dividends, it will result in present loss to an over-greedy corporation. To the prudent and well-managed company and to new capital seeking opportunity for investment in public service works, it will give added safety and be attractive.

In conclusion, the writer desires to make grateful acknowledgment of his obligation to Messrs. Allen Hazen, William Wheeler, Harrison P. Eddy and Charles W. Sherman, Members, Am. Soc. C. E., for friendly suggestions upon this paper, and to Hon. Herbert M. Heath, of Augusta, Maine, Corporation Counsel, for permission to make use of portions of the arguments advanced by him in the Maine case cited.

DISCUSSION

C. S. Burns, M. Am. Soc. C. E. (by letter).—This paper will be read with interest, and those engaged in valuation work will be grateful for the added light thrown upon a subject which has been enveloped in ambiguity. Doubtless no subject of equal importance has caused more diversity of opinion among experts than this question of valuation of quasi-public utilities. The Brunswick opinion, cited by the author, is especially interesting, as it represents the amended ideas of an eminent judge after further consideration of a subject previously studied, presumably with considerable care. Even in the Maine decisions, however, some rules are prescribed which upon close analysis appear to lead to ambiguity and to conflicting results relative to franchise value. Mr. Burns.

It seems clear that franchise value cannot be considered in determining reasonableness of rates, because the franchise has no value, other than the opportunity that it creates for the safe investment of capital, and, unless the capital thus invested produces returns greater than the market rate fixed by the law of supply and demand, then the franchise has no value, while, on the other hand, if the rates are higher than fixed by the law of supply and demand regulating the investment of capital in similar undertakings, then they are unreasonable by just that much. In other words, franchise value is the measure of the unreasonableness of the rates, and neither can exist unless the other is present. Moreover, it requires an unusual stretch of the imagination to conceive of a condition of affairs that could justify a city or town in paying for a franchise to occupy its own streets simply because that privilege had been previously extended to a corporation. If the municipality reimburses the corporation to the extent of what the property is actually worth to the city, including a fair estimate of the expense that the city would have to incur to develop the business, there can be no reasonable grounds for complaint.

To state that "the reasonableness of the rates relates to both the owner and the customer, but in case of conflict the rates must in any event be reasonable to the customer", followed by the stipulation, "A public service company cannot lawfully charge more than the services are reasonably worth to the public as individuals, even if charges so limited would fail to produce a fair return to the owner upon his property or investment," is unquestionably correct. If pursued to its logical conclusion, this theory would seem to require the consideration of evidence to show what the cost would be to the consumer, if permitted to serve himself by the substitution of another equally efficient, or different, structure to do the same work; and, in the light of the further statement, that "Communities are entitled to the benefit of natural advantages, and the company is not entitled to charge en-

Mr. Burns. hanced rates based upon the cost of using the more expensive source," it is difficult to understand why the testimony covering this point in the Portland case was not given consideration in conformity with the above rulings.

The original cost is frequently brought forward and unduly emphasized by corporation experts, with the plea that the valuation of the property should not be less than it cost the company, less proper allowance for depreciation.

However, the original cost should have no more consideration, in the case of a company having built works under difficulties and at a time of abnormal prices of material and labor, than it should under the reverse condition, or in case of a company having purchased a property at foreclosure sale at a small fraction of its structure value. If a property having a structure value of $100 000 were purchased by a private company for $25 000, it would manifestly be unjust for the municipality to take it at a later date under an appraisement based upon the original cost of $25 000, thereby taking advantage of the company's good fortune in having been able to acquire the property at a bargain at a time when, perhaps, the municipality could not have purchased the works so advantageously, if at all. On the other hand, it is equally unjust to require the municipality to pay an exorbitant price for a property based on an original cost loaded with promotors' fees, excessive bond discounts, or unreasonable construction cost of any nature, whether it be due to high prices of material, poor management, lack of engineering investigation, or what not.

If a company undertakes the construction of a water-works system when prices are abnormally high, and is willing to finance the project with such disadvantageous conditions, under a franchise granting the municipality the option of purchase by appraisement, it does so of its own free will, and should not complain subsequently if its property be appraised at market prices differing from the original cost.

It is true that the "reproduction cost" has always been recognized as pertinent and important, though not controlling, in valuation cases. Why should it not be controlling in determining the price that should be paid for the property in case of purchase by the municipality?

Reasonableness of rates could not well be determined by this procedure, because there would result a continuously changing system of rates, which would be impractical of application, and, therefore, the only practical basis of valuation for rate-fixing purposes should be the average prices extending through a period of years, or what might be termed the normal prices. Normal prices appear to be the proper basis of valuation to be used in fixing rates, but not so in the purchase of the property.

When a municipality decides to exercise its prerogative and purchase a water-works system, as provided under the terms of the fran-

chise, it is entirely practical to appraise the works on the basis of current prices, and it seems proper to compute the reproduction cost on that basis, and use that result with proper allowance for depreciation (both physical and functional), as the correct valuation of the plant. Whether the result thus found is greater or less than what it would have been a year previous, or what it might be at some future time, is a mere incident, and should have no influence in the case. If the municipality elects to purchase the property at the present time, it should pay the present value, whether that be greater or less than the normal or average value. In fact, it can make but little difference, either to the purchaser or the seller, whether an appraisement be made at high prices or low prices, providing the prices used are current and up to date; but to use prices of a year or two ago may be of the greatest injustice to one of the parties. It would be interesting to know what special arguments were offered *pro* and *con,* to cause the ruling of the Maine Courts fixing the assumption of prices prevailing at a time long enough prior to the date of taking to cover the probable period of construction. Mr. Burns.

It is universally true that, when prices are abnormally low, rates of interest are high, and *vice versa;* the law of economics is an equalizing force affecting both the seller and the purchaser. By way of illustration —using the Portland case cited by the author—suppose the price of cast-iron pipe had been taken at the rate prevailing at the date of taking. The reproduction cost would have been $80 000 less than it was found to be under the Maine ruling requiring the price to be assumed at the market rates of two or three years prior.

The author does not present data to show the relative rates of interest that the city would have had to pay upon the bonded debt at the two periods in question, but the financial conditions throughout the country have been such that it is safe to predict that the municipality should have been given the benefit of the reduced price of material; and, even after making the $80 000 reduction, the actual annual interest paid by the municipality on the bonds issued (assuming the plant to have been bought with the proceeds of a bond isue) would have exceeded the interest paid on the larger bond issue two years prior.

Again, considered from the standpoint of the seller, there seems to be no reason in equity why the plant should be valued upon prices other than those in vogue at the immediate date of sale. If prices are low, he has the opportunity to reinvest his capital in similar enterprises at those very same prices; hence, no injustice has been done by using the current prices. Why should the valuation be based on prices of a year or two prior, when the opportunity for reinvestment at those prices has long since gone by? Suppose the city, in purchasing pipe two years ago at $29 per ton, ordered a surplus of pipe, and stored

Mr. Burns.

this surplus pipe in the warehouse. Certainly no one would argue that this stock on hand is worth $4 per ton more than new pipe, and yet such an argument would be just as sound as to say that the pipe in the ground is worth $29 per ton now simply because the municipality would have had to pay that price for it two years ago.

There can be no rule or guide to the appraiser more fair than the principle quoted by the author: "The worth of the service to the consumer." This rule, intelligently applied, should be applicable in determining "fair rates" as well as present value for transfer of the property.

It is to be hoped that discussion will follow concerning functional depreciation, covering some of the customarily disputed points. Water companies have frequently employed able engineering advisers who have produced every possible argument to swell the value of the property, while the municipalities have as frequently failed to appreciate the necessity or value of such assistance, leaving the matter in the hands of some local attorney who finds himself overwhelmed with evidence beyond his comprehension, and is unable to meet the arguments. The result has been that many unsound arguments have passed unchallenged, and methods of calculating present values wholly favorable to the corporation interest have prevailed so frequently as to have become classic and accepted without question or serious combat.

An example of this condition of affairs is illustrated by a recent case where the water company's expert maintained that a proper item to be considered in the cost of reproduction is the presence of a street railway located directly over the pipe line. He argued that the extra cost of taking up and relaying the track should be added as an item of value, on the theory that such expense would necessarily be incurred in duplicating the system. It is needless to say that the city's adviser easily combatted the argument by the mere statement that the pipe line need not be located under the track, is worth less by virtue of such location, and would not be thus located were the city to build its own plant.

But what about street paving? Appraisers have quite uniformly agreed upon the fairness of allowing extra value to a pipe lying beneath a paved street. But why do so, unless it is necessary for the pipe to be thus located? If the franchise provides that the paving over the pipe shall be laid and maintained at the expense of the water company, then it would be fair and equitable to allow extra for the paving; but, in the absence of such a provision, there can be no equity in allowing extra therefor, thus requiring the municipality to pay a foreign company a double premium upon an item for which the city itself has already paid.

It seems to be more logical to treat street paving as a cause for functional depreciation, for, if a pipe line lies under a paving, it certainly costs more to maintain it, every street connection that requires

Mr. Burns.

INTEREST AT FOUR PER CENT ON CONSTRUCTION DEBT.
RENEWAL FUND INVESTED AT TWO PER CENT PER ANNUM AT
BEGINING OF EACH YEAR.

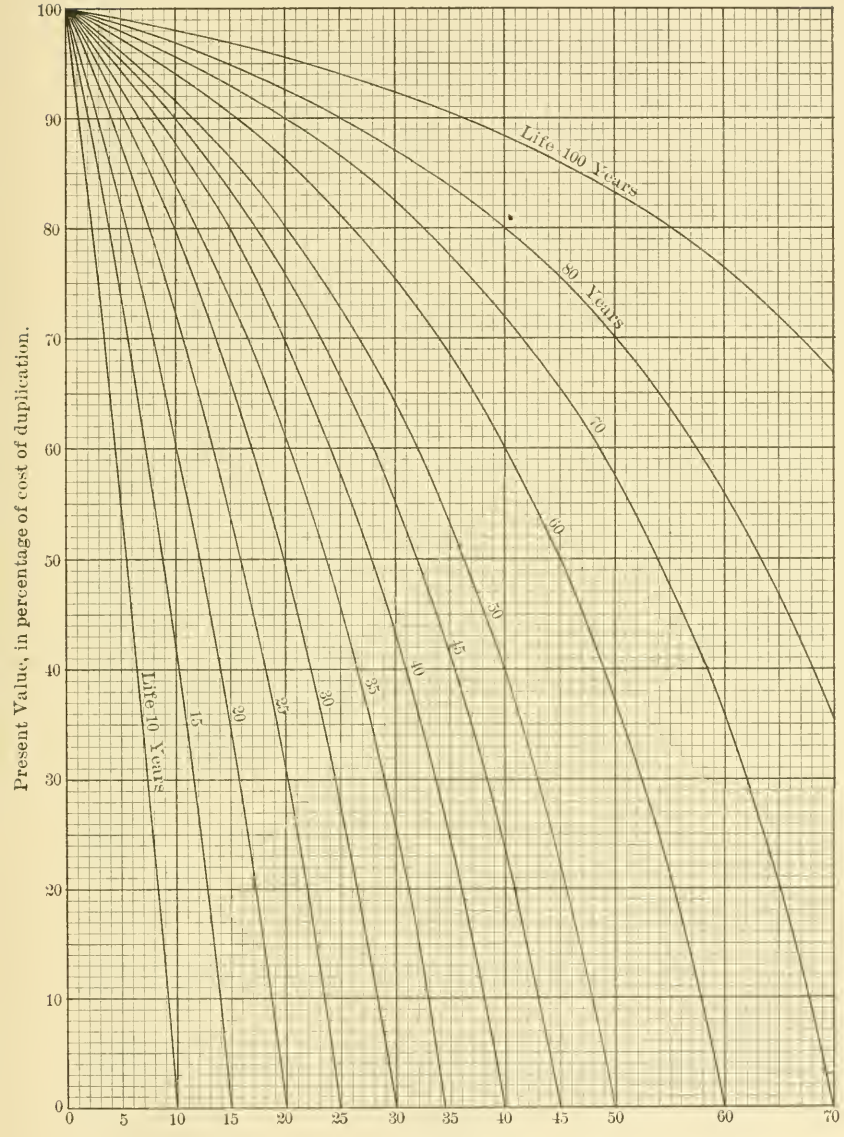

FIG. 1.

Mr. Burns. repairs is more inaccessible, and, in fact, the street paving is decidedly an objection to the water-works system. If the pipe line could as well be laid between the sidewalk and the curb line, as is usually the case in residence districts, or in the alleys in commercial districts, thereby avoiding the paved streets, then the paving should be treated as an item of depreciation rather than contrariwise.

If an investor were purchasing a water-works system, it is doubtful if he would be inclined to pay any more on account of the pipes being covered with an expensive street paving; indeed, if the franchise required the water company to take up and replace all paving disturbed in connection with excavations for repairs, the prospective purchaser would insist upon a smaller price on account of the street paving.

Regarding physical depreciation, there can be no more fair method of calculation than to compute the annual cost of a new article, and ascertain what value of the old article will give the same annual cost to the user. By long established custom, interest is payable annually, taxes are collected annually, and the year is a convenient unit of time to use in the calculation.

Accepting the above hypothesis, the present value of any article, or machine, may be defined as that sum which will make its annual cost to the taxpayer, or user, the same as the annual cost of a new machine capable of doing the same work. The annual cost of any machine is the interest on its capital cost, plus the annual charge for renewal fund, plus the cost of maintenance and operation (if any).

The renewal fund is that sum which, placed at compound interest annually, will amount to a total sum at the end of the life of the machine sufficient to replace it. As a simple illustration, take a standpipe twenty years old, the total life of which is estimated to be thirty years, the cost of maintenance and operation being the same for an old structure as for a new one, assuming no functional depreciation to have taken place due to the growth of the town or changed local requirements. Assume the cost of a new structure to be $10 000. Then the annual cost of a new structure is as follows:

Interest on the capital investment at, say, 5%	$500.00
Annual renewal fund invested at, say, 3% = 2.1019%	210.19
Annual cost of maintenance (painting, etc.) = K.	
Total annual cost	K + $710.19

For a similar structure twenty years old, having ten years yet to serve, its present value being the unknown quantity, x, the annual cost is as follows:

Interest on capital investment, 5%	$0.050000 x
Annual renewal fund (10 years life, 3% basis)	0.087231 x
Annual cost of maintenance, as before, = K.	
Total annual cost	K + $0.137231 x

Hence $K + 0.137231\ x = 710.19 + K$, from which x, the present value, equals 5175.14 or 51¾% of the cost of a new structure. Mr. Burns.

The present value in percentage of the cost of a new structure could as well be determined directly by the ratio $\frac{5 + 2.1019}{5 + 8.7231} = 51\frac{3}{4}\%$, based on the author's sinking-fund data, Table 1. These results can be computed rapidly from sinking-fund tables with the aid of the slide-rule.

To facilitate calculations of this nature, the writer has constructed nine diagrams by the above method, and from these the present value may be read directly as a percentage of the cost of duplication. One of these diagrams is reproduced herein as Fig. 1. These results will differ slightly from the author's tables, as the renewal fund has been assumed to be invested at the beginning of each year instead of at the year's end. The reason for this is that most statutes provide for the collection of taxes at the beginning of the year, and the renewal fund is nearly always collected in time to be invested at least as soon as the structure is completed and put into service.

The diagrams have been constructed for 2, 2½ and 3% for renewal fund investments, and for 4, 5 and 6% interest on capital investment. Before these diagrams were prepared, in 1905, letters were sent to fifteen of the leading banks and trust companies of Kansas City, St. Louis, Chicago, and New York, to ascertain what rate of interest each would agree to pay upon a sinking fund, contributed at the beginning of each year for twenty years, or more, and the replies ranged from 2½ to 3%, the fund being protected by surety bond at the expense of the bank in each instance.

If the article for which the present value is sought is a machine the cost of operation of which is dependent on its physical condition, this factor must be introduced into the calculation, and correction must be made therefor before applying the diagrams.

It may appear to some that this discussion is unduly partial to the municipality. It is not thus intended, although it must be apparent, to those who have followed the subject closely, that the corporation interests have developed their side of the subject far more skilfully than have the municipalities, due to the short-sighted policy of so many city officials in failing to employ competent experts to aid their legal advisers. Court decisions are based upon evidence, and influenced by argument, consequently it is but natural that the greater number of cases have brought forth decisions favorable to the party best prepared for argument.

James Nisbet Hazlehurst, M. Am. Soc. C. E. (by letter).—The writer is particularly interested in the sub-topic "Monopoly Value of Land and Water Rights."* Mr. Hazlehurst.

* Page 26.

Mr. Hazlehurst.

As has been pointed out, the term "Monopoly Value" is loosely applied in such cases, since, from the franchise, the power, right, or privilege to sell water as a commodity may or may not be exclusive, depending on the precise terms of the grant, and, if exclusive, its duration in time may clearly affect such monopolistic value. While the courts have generally held that the exclusive right to sell water to a city by individuals or corporations must not have for its object the creation of a monopoly, and cannot be enforced, yet certain cases may be recited showing a shadowy line of demarcation, as for instance, the case of Oakes *v.* Cattaraugus Water Company (N. Y.), 38 N. E. Rys., 461, wherein an agreement to refrain from forming a corporation for the construction of water-works and from carrying on or prosecuting such work in such manner that another may incorporate for that purpose without competition is not void as against public policy.

"Contracts in general for total restraint of trade, or contracts for the purpose of creating a monopoly, or compacts having for their object the elevation or depression of the market prices, or to raise or lower the prices of goods and produce, or sales of stocks, grain, and produce on margins, or option contracts whose effect is to corner the markets, are held to be against public policy and void."*

Under the franchise rights, then, it seems that even a limited monopoly by legislative enactment may be voided as against public policy, and this increment of value ceases when the monopolistic right no longer exists; but a monopoly value, predicated upon exclusive possession, is a factor that may be of prime importance and of great intrinsic value.

The business acumen or foresight of an individual or public service corporation in acquiring for use, as a necessary item or element, an advantageous or even exclusive source of water supply, impounding-basin, water-shed or reservoir site, constitutes a natural monopoly. It is obvious that such possession would have a value commensurate with its present and prospective use under lawful restrictions.

During the full possession and exercise of its franchise rights to supply water to a community, it would seem clear that where, either through the condemnation right of eminent domain or by arbitrament, a municipality seeks to possess itself of the property enjoyed by an individual or corporation with vested rights, the value of any natural monopoly should be given due weight.

Under such circumstances, the worth of this particular item to the community and its value to the owner should be established by evidence, and, to the writer, it would seem that in equity this worth or value is represented by the capitalized cost of construction to a more remote source of supply or less accessible and more expensive natural location. Perhaps in an unusual case, where such source or location

* "Engineering and Architectural Jurisprudence," p. 72.

is in fact an actual monopoly, its value might be predicated upon actual and prospective net earnings capitalized, but hardly in perpetuity. Mr. Hazlehurst.

Under such conditions, monopolistic worth to a community is exactly the same as the value of the item to any one else, and the fact of the franchise grant or gift originally being derived from the public is not reason for abatement of specific value in the case of such natural monopoly.

As against these averments, a legal differentiation might apply to a case where the franchise grant had expired by limitation and where a municipality declined to renew the same or to permit a transfer of ownership with extension rights. Such situation would presuppose a desire for municipal ownership, and this public sentiment and attitude would in effect deprive a natural monopoly of its value as such; nevertheless, the acquisition of property under such circumstances would, at least in equity, seem to partake of proscription and confiscation without due recompense, contrary to good morals, if not to sound public policy.

Arbitrary acts and sharp practice should be decried alike in the individual and the community, and public policy as well as a high moral conception should direct opinion so as to prevent an unfair treatment of vested rights in the interest of private or public gain, and especially should this be so where an endeavor is made to destroy values of such quasi-public enterprise as a water-supply plant.

As a specific case, coming within the knowledge of the writer, and illustrating the right of a municipality to secure to its use through condemnation certain items, features, or interests, excerpts are made from the case of Wood *v.* City of Mobile, Circuit Court, S. D., Ala., February 8th, 1900; appealed April 2d, 1901:

"The legislature of the State of Alabama by an act approved Nov. 30th, 1898, authorized the City of Mobile to provide, maintain, and operate systems of water-works and sewerage; and by act approved Nov. 30th, 1898, authorized the City of Mobile to make and issue bonds for building, purchasing or otherwise acquiring systems of water-works, and to secure said bonds; and by an act approved Dec. 10th, 1898, authorized the City of Mobile to condemn by eminent domain the outstanding interest in what is known as the 'Mobile City Water-Works;' under the statutes, the City of Mobile condemned, by exercising the right of eminent domain, and the interest of Walter Wood in what is known as the 'City or Stein Water-Works,' such interest being $54\frac{28}{100}\%$ of the whole. The decree of the Probate Court condemned the lands for public use, and vested the title in the city, all and singular, the perpetual right to all the interest of every kind, character and description belonging to Walter Wood of Philadelphia, Pennsylvania, whether the same be legal or equitable in and to those water-works known as the 'Mobile City Water-Works.'"

Under the theory that the proceedings in the Probate Court were void, the plaintiff instituted in the lower Court an action of ejectment

Mr. Hazlehurst.

to recover possession. Under this plea, the plaintiff, Wood, contended that:

"The Probate Court had jurisdiction and power to condemn by eminent domain only so much of the land and such interest in the property and lands of the plaintiff as were necessary for the use of the new water-works system, and that only an easement or right-of-way over such lands as it actually needed for the construction of its new water-works system could be condemned by the city, and that, in so far as the decree of the Probate Court went beyond this, it was absolutely void and passed no title to the city; and further, that even if the property was legally condemned, yet if part of it was never used by the city for the public benefit, such part reverted to the original owner, and he could receive it back in ejectment."

Held in Part by the Court.—"As to the contention that part of the property of the old Stein Water-Works has reverted to the original owner because of non-user after condemnation, it may be admitted that the general rule is that when a corporation, in the exercise of eminent domain, acquires for a public purpose an easement in land, its right and title to the property so acquired are dependent upon the use of the property for public purposes; and, when such public use is abandoned, the right to hold the land ceases, and the property reverts to its original owner. But the plaintiff in error in that case can take nothing under this admitted rule, for two reasons: First, under the statute of Dec. 10th, 1898, more than an easement was condemned; to-wit, all the right, title and interest, legal and equitable, on the basis of which full title it is supposed the owner was fully compensated, and the property thereupon became the absolute property of the corporation; second, because, in the agreed statement of facts in this case, it is expressly admitted that 'the City of Mobile has used, and is still using, the whole of the property and franchises acquired from the plaintiff in error to supply water to the citizens of Mobile, and that the said Mobile City Water-Works are now connected by iron pipes with the new water-works system built by the City of Mobile under the act of the general assembly of Alabama, approved November 30th, 1898.'"

In this cause the plaintiff sought to establish the fact that, only an easement being necessary to the City of Mobile, it could only condemn a right of way over lands in controversy, maintaining that any item or property not actually required for the public use should revert to the original owner. The admissions in the case seem fully to justify the decree.

Considering the converse, where the effort is to force upon a municipality, exercising the right of eminent domain, all and sundry items, some of which are perhaps undesirable or unnecessary to its use, it would seem that in such matter the principle may be applied toward the acquisition of some natural monopoly or coveted feature, neglecting other items whereby their value may be depreciated or destroyed, provided values be considered broadly, the appraisement being based on existing conditions and determined facts, and with due regard to

the principle that, after sucking the orange or skimming the cream, values both of the substance taken and remnant left must, in all equity, enter into the final consideration. Mr. Hazlehurst.

ALLEN HAZEN, M. AM. SOC. C. E.—The speaker is very much interested in the subject of water-works valuations, and was fortunate in being able to read a large part of the manuscript for this paper and to talk over various matters with Mr. Metcalf during its preparation. Mr. Hazen.

The decisions of the Maine Courts have certainly thrown a great deal of light upon the methods of valuing water-works properties, and the speaker is extremely glad that these matters have been presented to the Society.

T. H. MCKENZIE, M. AM. SOC. C. E.—There are various purposes for which a water-works property must be valued or appraised, the most common purpose being for taxation. Most of the larger water-works systems lie in several towns or municipalities, and the first question that comes up is whether reservoirs and pipes in the ground and water rights in streams are real estate or personal property. Mr. McKenzie.

If a water-works system is to be valued as a whole for the purpose of sale, it is an easier matter to arrive at a proper value than to determine the value of a reservoir or of a mile of pipe crossing a town other than the one in which the water is used.

The best method of arriving at the market value is to base it on the net income after deducting a proper amount for a sinking fund to provide for renewals and maintenance. As a rule, in flourishing cities and towns, the franchise, water rights, and reservoirs, increase in value faster than the distribution system depreciates, so that the market value of any of the best works is more than the original cost.

Most of the private water corporations have built their works because cities and towns or other municipal corporations have considered that such works would not be a paying investment; and, when private companies have raised the capital and built the works without much hope of income they should be paid much more than the cost, in the event of the works being acquired by a municipality. The works should be paid for about on the basis of appraisals under the Mill Act or Flowage Act in the State of Connecticut, which requires that after the return of the appraisal to the Court the Judge shall add 50% to the value as appraised.

Being Treasurer and Manager of a works which lies in two towns, the speaker is more interested in the valuation of water-works for taxation than for the sale of the entire plant. Not more than one-third of the property of the company lies within the municipality or Borough where the office is located, and about 60% of it lies within the Town where the office is located, yet the company is taxed for the same amount

Mr. McKenzie. in the Borough and Town, the works being classed as personal property and taxable where the office of the company is located. The assessors of the adjoining town have a different theory—they say the property is real estate and tax the company again in their town; and the Courts will soon have to determine whether the water-works, pipes, reservoirs, and other fixtures, are real estate or personal property.

Mr. Tribus. L. L. Tribus, M. Am. Soc. C. E.—The author should be congratulated on having presented the subject in so exhaustive and comprehensive a manner, and the Society may be congratulated on being able to present to its membership the information so carefully compiled and submitted for discussion; as a review of the subject, it is almost beyond criticism, covering apparently every phase of water-works valuation.

This is a question that is yearly coming into greater prominence and importance, as more municipalities are taking over private water plants and more States are requiring valuations of public service plants for taxation purposes—a very difficult branch of the subject to handle satisfactorily.

While rules of law can be laid down covering certain features of procedure and many theories can be advanced as to the methods of valuing water plants, in the last analysis the award to a company, where a community has the power to condemn, should be simply a common-sense agreement to pay such sum as shall represent practically a mean between the earning value of the plant to the company and the value to the community, provided the plant has been in operation for a long enough time to have given a reasonable return upon the investment. A community should bear in mind the usual fact that its own citizens have invested money in a local enterprise and are entitled to reasonable protection against arbitrary wrecking of the investment; on the other hand, the larger number of citizens are entitled to consideration in not being called upon to pay an award that gives an undue return to others.

Probably it will never be possible to establish a code of rules according to which a water plant can be valued in condemnation proceedings. In almost all cases local circumstances will have such a peculiar bearing upon the case as to control an award to a greater degree than would be the difference in results secured in adopting different systems of valuation. The unbiased expert will always be needed, but his opinion will only be of value if his mind is free to adapt or adopt any method that may have special bearing on the case at issue.

The author has referred to a feature in valuation work not often considered, namely, the liability of a water company for damages due to inefficient fire service, where a company is under public or

private contract to furnish such service. Another liability, not mentioned by the author, which has been passed upon in at least one court, a review of the case being given herewith, is the responsibility of a water company to render at all times adequate service to private consumers, taking into reasonable consideration, of course, special accidents or causes beyond the company's control. Mr. Tribus.

SUPREME COURT, STATE OF NEW YORK,
APPELLATE DIVISION—SECOND JUDICIAL DEPARTMENT.

GEORGE M. WHITEHOUSE,
Appellant,
AGAINST
THE STATEN ISLAND WATER SUPPLY COMPANY,
Respondent.

APPEAL by the plaintiff from a judgment of the Municipal Court of the City of New York, First District of the Borough of Richmond, rendered on the 2d day of June, 1904, dismissing the complaint on the merits.

HOWARD R. BAYNE, for the Appellant.

T. LUDLOW CHRYSTIE, for the Respondent.

HOOKER, *J.*:

The defendant was successful in the Municipal Court in an action brought by the plaintiff to recover damages for its failure to supply him with water during the months of January and February, 1904. The plaintiff has appealed.

The defendant is a domestic corporation, duly organized under chapter 737 of the laws of 1873, and the laws supplementary thereto and amendatory thereof, for the purpose of supplying the inhabitants of the Village of New Brighton with pure and wholesome water at reasonable rates.

Pursuant to provisions of chapter 378 of the laws of 1897 the Village of New Brighton was consolidated into the present City of New York. For many years the plaintiff has occupied as a dwelling-house premises located on Hamilton Avenue in New Brighton, and since the consolidation has resided at the same place, in what is now called the Borough of Richmond in the City of New York. For nearly twenty years prior to the first of May, 1903, the plaintiff was a consumer, at his residence on Hamilton Avenue, New Brighton, in the present Borough of Richmond, of the water supplied by the defendant, and on or about that day the plaintiff paid to the defendant the rate for which the defendant promised and agreed to supply him under the usual conditions with water for the ensuing year. During part of the months of January and February, 1904, however, the defendant failed to supply the plaintiff with water. During part of this time the supply was quite insufficient, and during the balance he procured no appreciable quantity of water from it, and in order to obtain water for his necessary domestic uses he was compelled to employ labor and apparatus to draw water from a cistern into a tank in his house, and the plaintiff claims to be damaged to the extent of the

Mr. Tribus. fair value of the labor he employed. There is no dispute on the question that during a considerable period of the month of January and a portion of the month of February, 1904, the plaintiff failed to receive water through the pipes from the defendant's supply, and no evidence was offered tending to contradict that of the plaintiff, showing the measure of his damage.

The principal question presented by the record for the consideration of the court is whether, under the contract existing between the parties to this action, the defendant's failure to supply water to the plaintiff during a considerable portion of the month of January and a part of the month of February, 1904, was a breach of that contract, for which the plaintiff is entitled to recover as damages the fair value of services rendered to the plaintiff in pumping water from his cistern for his use. The defendant is a *quasi*-public corporation, chartered to supply water to citizens of what was formerly New Brighton. When the plaintiff moved into his present residence, connection had been made between that residence and the defendant's main in St. Mark's Place by means of a service pipe, and upon the plaintiff taking up his residence there he paid to the defendant the sum of money it asked each year for the supply of water which he proposed to use. The rate was readjusted after he had lived there a short time, for the reason that he thought he was paying a larger rate than the regulations of the defendant called for. One of defendant's agents, upon the basis of the established rates, took an inventory of what the plaintiff was using, and readjusted the rate. This rate was paid for many years, and on or about the first day of May, 1903, the plaintiff again paid to the defendant and the latter received the annual rental. Under these circumstances a contract is implied between the plaintiff and the defendant corporation by virtue of which it undertakes to supply him with water. (McEntee *v.* Kingston Water Co., 165 N. Y., 27.) There must necessarily be implied in this contract a provision that the supply by the defendant for which the plaintiff is paying shall be sufficient for the ordinary uses to which the plaintiff has put it. It is unquestioned that there has been a breach of that contract, and the measure of damages adopted by the plaintiff is not, nor could it well be, questioned. The defendant sought to escape liability on the theory that the contract with the plaintiff was simply to supply water at the junction of the service pipe and the water main in St. Mark's Place, and that because the plaintiff's residence was on an eminence and at an altitude considerably above other premises supplied from the St. Mark's Place main, it was not liable, provided it could show that water could have been obtained from the junction of the main and the service pipe. Such was not the contract between the parties. Were such provision properly to be incorporated into an implied contract between water companies and consumers, it would, at the option of the water company, relieve it from all liability for its failure to force water into the houses of its consumers, by showing that water could have been obtained in the street below ground in the water mains. The implied contract in this case was to supply the plaintiff with water, no matter what the altitude of his house was above the water main; for this had been the custom for many years, and the defendant had been paid the rates demanded for supplying

water at the house; and again in continuance of the contract, on the first day of May, 1903, the defendant accepted payment of the full rate for the ensuing year, which implied a contract to continue the service as it had been rendered, and that was that the plaintiff should have water in his house. Mr. Tribus.

The only other defence relied upon by the defendant, namely, that owing to the excessive cold weather the defendant had been unable to maintain its usual pressure on account of the fact that the water taps of consumers were generally open and allowed to remain so to keep up a circulation of water for the purpose of preventing freezing, is not sufficient to relieve the defendant of liability. The action is not one of negligence, but to recover damages for a breach of a contract, and where a contract is absolute the *vis major* is not an excuse for non-performance. (Harmony *v.* Bingham, 12 N. Y., 99; Ward *v.* H. R. B. Co., 125 N. Y., 230.) It is to be observed that one of the rules and regulations of the defendant company, incorporated into the contract between it and its consumers and numbered section 12, on the reverse side of the water receipts, reads as follows: "It is mutually understood and agreed that faucets are not to be left open to prevent frosting of pipe in cold weather, nor to obtain cool water in warm weather." Such a regulation appears on its face to be reasonable, and it is clear therefrom that the defendant had adopted the same so that it might prevent the occurrence of such a condition as it now claims was accountable for the failure of the plaintiff to obtain water during this cold weather. Our opinion is that, although the circumstance is not in any event a defence to this action, the defendant should not be allowed here to take advantage of its failure to enforce one of its own regulations, enacted for the purpose of its preventing the occurrence complained of.

For these reasons, the judgment should be reversed and a new trial granted, costs to abide the event.

For many years George M. Whitehouse, the plaintiff, in the original action against the Staten Island Water Supply Company, received water at his residence from the mains of said company, but as years went on the service rendered by said company became very poor and at times ceased entirely, not due to special emergency or accident.

The company continued to charge annual rates for full service. The plaintiff objected, and finally brought an action, practically all salient features being rehearsed in the opinion of the Court handed down by the Appellate Division, Second Judicial Department.

The decision of the Municipal Court, in which the original action was brought, was in favor of the defendant, the Staten Island Water Supply Company. An appeal was taken, resulting in a reversal of the judgment and the granting of a new trial, costs to abide the event. The second trial in the Municipal Court came on, with judgment being rendered in favor of the plaintiff.

The water company then appealed to the Appellate Division, but judgment was unanimously affirmed, without opinion. The water

Mr. Tribus. company subsequently moved for leave to go to the Court of Appeals, but the motion was unanimously denied, which ended the litigation, and the water company paid the judgment, including costs and interest in full. The opinion, however, previously referred to as handed down on the first appeal, covers all salient features of the case, and is worth reproduction as a matter of general interest.

Mr. Williams. GARDNER S. WILLIAMS, M. AM. SOC. C. E.—There are one or two matters—perhaps more in the light of detail—that might be mentioned, not, however, in the way of criticism, for, like those who have preceded him, the speaker feels that the subject has been treated very satisfactorily by the author, and that the Society is to be congratulated upon having it thus presented. It may be interesting, however, to contrast the rulings of the two courts which have been cited. One sees in them the influences, on the one hand, of the democratic government of early New England and, on the other, of the proprietary control of early Pennsylvania. The theory of the New England ruling is evidently that the franchise of the public service corporation is practically exclusive, or that it is not subject to competition, and on that theory the public has a right to demand that the service be reasonable in return for the exclusiveness which, virtually, has been granted. If the Pennsylvania theory, that the corporation is entitled to a return upon whatever it has invested, be adopted, then naturally the only relief the public has is in competition, and it seems doubtful whether the theory of exclusiveness could be maintained on the basis of the Pennsylvania ruling.

Those who are familiar with the effects of non-exclusiveness in public service corporations will probably prefer to accept the New England view.

The author's method of treating the going-concern value may be modified a little by considering it as part of the expense of the creation of the works, and allowing the income to cover the interest upon that as well as the remainder of the investment. That is, to charge to the capital account the cost of developing the properties. This seems to simplify the matter a little, for then there would be only two cases of going-concern value to consider, whereas, under the author's treatment, there are three. If this investment in developing the going concern is treated as capital, the capital is entitled to earn interest, and the third case, wherein the plant has paid back that investment, is eliminated.

A point to be considered in determining the reasonableness of rates is the proportion of the income of the works which is derived from the public at large, from the general tax levy, as distinguished from that which is derived from the consumers. Very often one fails to distinguish between the relation which the consumer bears to the plant and the relation which the general public bears to it. In connection with every water-works system, there are certain functions the per-

formance of which inures solely to the benefit of the public at large, and are entirely distinguished from the service to the consumer. The cost of rendering such service, for example particularly fire protection, should be borne by the general tax levy and not by the water consumer, because the amount of fire protection that a property requires bears no necessary relation to the amount of water that may be there used for other purposes; and oftentimes it occurs that rates may appear to be excessive against the consumer, when, if the municipality, through the general tax levy, were bearing its proper share of the burden, the rate which would then have to be raised from the consumer would not be excessive, and the income of the company might still be equitable and just, although the distribution of it between its two sources might be inequitable. Mr. Williams.

Another question which arises frequently is that of the rate of interest allowed on the sinking fund. In the case of municipal corporations the law usually requires that a certain sum be set aside periodically and invested in reliable securities at whatever rate of interest can be procured; but, with a private corporation, the sinking fund, if it exists at all, is generally invested in the plant itself, and the rate of interest which it earns is the same as the earning capacity of the works. This point is generally overlooked in valuations, and the sinking fund interest is figured at 5 or 6%, when, very often, the money that represents the sinking fund has been earning, not 6 or 7%, but more probably 10 or 12%, and quite properly so, because it is getting the benefit of the earnings of the property itself.

The author, in discussing depreciation, calls attention to what he calls obsolescence, being that depreciation which is due to the fact that the particular piece of apparatus, though it has not worn out, is no longer of value because there is something so much better that one cannot afford to use the original article. Those who are familiar with the development of electrical apparatus know that a machine that is in good repair and as good practically as it ever was, so far as performing its work is concerned, may not be worth using at all to-day, because there is some other machine which has been more recently perfected that can do the same thing so much more economically that one simply has to throw the old machine into the scrap heap and use the newer invention. The same thing occurs in a way in all machinery, and it is that condition to which the author refers as obsolescence. If there be such a thing as obsolescence, and all must admit that there is, it seems that there must be its antithesis, or non-obsolescence; in other words, there is a situation where the thing cannot depreciate.

As an example, consider a line of pipe, say, 50 years old, more or less, which is sufficient for the work it has to do. It may be sufficient for all the work it will ever have to do, if the territory which it serves is developed to its fullest extent. In all large cities there are many

Mr. Williams. cases of that kind, many instances where the pipe in a single block will never be replaced, and is entirely satisfactory for what is required of it, and will so remain. Such being the case, that pipe, so far as its service is concerned, cannot depreciate any further. Moreover, whatever it cost in the first place, if it has arrived at this condition, that cost is to be looked upon as not subject to depreciation, but as the cost necessary to produce its present capacity. If, in the first place, it was a 6-in. pipe, and it has reduced its capacity until it is now a 4-in. pipe, and a 4-in. pipe is sufficient, then it is just as good as if it were a 6-in. pipe, and if one were building the plant again he would have to put in a 6-in. pipe in that place in order that it should be sufficient for its present requirements and for all future time.

That is an example of the antithesis of obsolescence; the pipe will not depreciate any more, and has not depreciated, since the 6-in. pipe was necessary for the future and would be similarly necessary now and will be necessary at any future time and sufficient all the time, in the condition in which it may from time to time exist.

Mr. Metcalf. LEONARD METCALF, M. AM. SOC. C. E. (by letter).—Since October, 1908, when this paper appeared in print, two important decisions have been handed down by the United States Supreme Court (simultaneously on January 4th, 1909), in the Knoxville *vs.* Knoxville Water Company and the Willcox (constituting the Public Service Commission of New York) *vs.* Consolidated Gas Company cases, which on account of their importance as the dictum of the highest court of the land upon the rating question, and of their direct application to the subject under discussion, are herewith presented by the writer.

A short sketch of the litigation leading up to the Water Company opinion is also included, in order to throw light upon this decision. The general interest in public service and rating questions, and the belief that the experience of the Knoxville Water Company is typical of the experience of many other public service corporations, is the writer's excuse for dwelling at some length upon the details leading up to the recent opinions.*

Since that date also, William S. Wallace, Esq., of Philadelphia, a corporation lawyer of wide experience in rating cases, has delivered before the 13th Annual Meeting of the Pennsylvania Water Works Association, held at Atlantic City, N. J., October 22d, 1908, an admirable paper upon "Expenditures for Future Needs as a Present Rate Factor, and Incidentally some Comments upon the Different Theories of a Reasonable Rate," in the course of which he discussed the two Maine decisions and outlined the difference between the Maine and the Pennsylvania decisions in their bearing upon reasonable rates. As Mr. Wallace has presented the matter so clearly and as his paper

* See page 101.

(which was not widely circulated and may be available to but few members of this Society) is so pertinent to this article, the writer takes the liberty of making some quotations from his statement: Mr. Metcalf.

"There seem to be two theories as to the proper basis for calculating reasonable rates for Water Companies, one, which I will designate the 'Ostensible Double Standard,' is well illustrated by the decisions of the Supreme Court of Maine; the other, which I will call the 'Straight Single Standard,' is exemplified by the decisions of the Supreme Court of Pennsylvania.

"In the case of Kennebec Water District *vs.* City of Waterville (97 Me., 185), the first named method is epitomized in this language by Mr. Justice Savage: 'The elemental principles thus far noted may be summarized as *on the one hand,* the right of the company to derive a fair income based upon the fair value of the property at the time it is being used for the public, taking into account the cost of maintenance or depreciation and current operating expenses, and *on the other hand* the right of the public to have no more exacted than the services in themselves are worth.'"

After quoting further from the Waterville and Brunswick decisions, Mr. Wallace observes that:

"To say that a Water Company must serve its customers in carrying out its public use, even without remuneration, seems next door to, if not justifying, confiscation without compensation. I will grant, as is laid down in the Penna. R. R. rate case (220 Pa., 100) that a public service corporation is bound to perform its corporate duties even at a loss, or else legally go out of business, but I at the same time contend this means a loss due to economic conditions—that is, those regulated by supply and demand—in other words, that there is not a sufficient supply of or demand for the services or product which the Company is chartered to render or supply to the public, to enable it to make a fair profit; not that if there is such a sufficient supply and demand to give the Company a fair return for its services at a fair valuation of its investment, it is nevertheless obliged to serve at a loss, because its customers as a public or municipality might, at the then time, serve themselves at a lower cost if they were to do something which they don't do and have no intention of doing, and often have not the power to do, to wit, raise the money, construct and operate their own works. Please note, also, that while this theory makes the value to the consumer the measure of the charge, the Company has no power to compel the consumer to take water if he does not desire to do so. If the Company is to be treated as if it were practically a public corporation, then the consumer should be obliged to support its service as he does in the case of a municipality by the taxes which he pays as a citizen.

"In short, as was said by Chief Justice Mitchell in the Penna. R. R. rate case, 'injustice is done by anything that fails to deal equitably with the *private* as well as the *public* interests involved. It (a fair profit) is not necessarily regulated by what others would *now* make the venture for under the present circumstances and with present knowledge.'

Mr. Metcalf. "Such a rule, if generally applied, would destroy all individual initiative in the way of developing public utilities, with the result, so far as water-works are concerned, that many places would have to go without that prime necessity and depend upon wells and like supplies, with all the attendant inconvenience and danger.

"While the Federal cases support this double standard (Smith *vs.* Ames, 169 U. S., 466; San Diego Co. *vs.* National City, 174 U. S., 757; Cotting *vs.* Stock Yards, 183 U. S., 79) and are cited by the Maine cases as the basis for the conclusions there stated, it should be noted that they seem hardly to go the length of those of Maine. Though in the Cotting case (*supra*) the Supreme Court holds that the value of the services to the consumer is the ultimate standard, they stop short of a theory which would, if carried to its logical conclusion, justify confiscation.

"Also in Palatka Water Works *vs.* City of Palatka, 127 Fed., 161, where the municipality claimed a contract right to fix rates, which, if anything, is stronger, the Court laid down the rule that: 'Even though defendant city has the right to regulate the charges to be made by complainant water company, for furnishing water to it and its citizens under a contract, the Court may interfere with rates so plainly and palpably unreasonable as to make their enforcement equivalent to depriving complainant of reasonable returns on its investments.'

"Turning now to the other theory as to the proper basis for a reasonable rate, or what I have denominated the 'Straight Single Standard,' probably the leading and most prominent illustration of this is found in our own Pennsylvania case of Brymer *vs.* Butler Water Co. (179 Pa., 231). In this case, Mr. Justice Williams, speaking for the Supreme Court, says: 'By what rule is the Court to determine what is reasonable and what is oppressive? Ordinarily, that is a reasonable charge or system of charges which yields a fair return upon the investment. Fixed charges and costs of maintenance and operation must first be provided for. Then the interests of the owners of the property are to be considered. They are entitled to a rate of return, if their property will earn it, not less than the legal rate of interest; and a system of charges that yields no more income than is fairly required to maintain the plant, pay fixed charges and operating expenses, provide a suitable sinking fund for the payment of debts, and pay a fair profit to the owners of the property cannot be said to be unreasonable. * * * The cost of water to the Company includes a fair return to the persons who furnished the capital for the construction of the plant in addition to an allowance annually of a sum sufficient to keep the plant in good repair and pay fixed charges and operating expenses. A rate of water rents that enables the Company to realize no more than this is *reasonable and just.*'

"In other words, the sole and single standard of a reasonable rate upon this theory is a fair return to the Company not less than the legal rate of interest after providing for costs of operation, maintenance, fixed charges and a sinking fund to pay debts. From which it seems to necessarily follow that a rate so fixed is not only to be considered reasonable to the Company but to the consumer as well, because it is made by this decision the measure of the value of the service to him. There is no qualification to this rule, except that the property 'must

earn it,' which reservation I take to mean, just what I have referred to above, that economically speaking the company must have capacity and business or consumers enough to produce the return. It must not only be able to, but must earn it, otherwise, it will perforce have to be satisfied with less profit and perhaps none at all, but such a condition has no bearing on or connection with the standard of reasonableness laid down, but results entirely from conditions of supply and demand. Mr. Metcalf.

"This single standard is entirely practicable. It does not mean, as I construe it, that if a company is chartered and able to supply a municipality of, say, 5 000 inhabitants and only 1 000 members of that community elect to take water from the Company, said 1 000 consumers must pay a rate which will realize to the Company not less than 6% on the value of the investment after deduction of operating expenses, fixed charges, depreciation, and sinking fund,* but rather that said 1 000 consumers shall pay *at* a rate which would produce the above return *if* the usual average of the entire community to be supplied took water. This average can be easily ascertained, and involves less figuring and uncertainty than the calculation of what the service is worth to the consumer under the double standard theory. Under the Act of 1874 the Courts are open to the consumer for such purpose or for otherwise adjusting the application of the rule to particular cases.

"As I have pointed out, the Double Standard basis of fixing a reasonable rate seems to accentuate the public side of the corporation and rather ignores the private element. * * * The Double Standard may seem ideal, but it is only so in theory. It is not practical, as is demonstrated by its resolving itself into a single Standard (hence my term 'ostensible') as soon as the two criterions conflict.

"On the other hand, the Single Standard, according to the Brymer case, while acknowledging the full right of the public to regulate such public corporations, also recognizes as a prime factor its private character and the rights which accrue to it in that capacity, * * * and holds to what seems to me the only rational and practicable basis, that a fair return after deducting the charges above enumerated *is* a reasonable rate."

Mr. Wallace's analysis is interesting. Practically, the results to be obtained by the application of the two methods may not be very different under the ordinary conditions existing in successful water-works projects, for, under the standard of the Maine cases, the works are rated on the basis of their value to the owner subject to the limitation of the worth (not cost) to the consumer, and under the Pennsylvania standard, on the basis of their earning capacity subject to the limitation of a reasonable regard for the public interest. In cases where the margin of profit to the investor is very close, the Pennsylvania method would seem to safeguard more amply the interests of

* The right to earn depreciation or a sinking fund is unquestionable. To earn "depreciation *and* a sinking fund" may be a matter of agreement and sound public policy, but is not a right. Moreover, does not Mr. Wallace overlook the desirability from the point of view of sound public policy, if not the right, of the Company to make good in its later and more prosperous years, through the agency of the rates, the losses usually sustained in the early years of the formative period of the new works?

Mr. Metcalf. private capital, and such safeguarding, within limits reasonable to the public, is believed by the writer to be good public policy.

In submitting methods for the computation of sinking-fund contributions, etc., the writer neglected to mention certain formulas which were worked up, at the request of the Boston Finance Commission, in his office by Richard K. Hale, Jun. Am. Soc. C. E., for the payment of serial bonds. The problem was to find the fixed annual sum which must be appropriated to cover the annual payment of interest upon the outstanding bonds, and the retirement of the bonds serially within the period covered by the bond issue, or, in other words, to determine the constant annual payment, X, to be made, to equalize the annual cost for interest upon outstanding bonds and payment upon principal account, such that the entire loan, a, would be paid off in n years; that is, in n annual payments with interest at the rate of r per cent.

Let X = The desired constant or uniform annual payment, in dollars;
Y = Part of principal to be paid off in any year;
Z = One year's interest upon the sum of the principal remaining unpaid and the portion of the principal, Y, paid upon the year under question;
a = Total value of bond issue;
n = Number of years which the bonds run;
r = Rate of interest upon the bonds;
b = Any year in which a portion of the principal, Y, is paid off.

$$X = \frac{a\,r}{(1+r)^n - 1} + a\,r \qquad (1)$$

$$Y = \frac{a\,r}{(1+r)^n - 1}\,(1+r)^{b-1} \qquad (2)$$

$$Z = a\,r\left[\frac{(1+r)^n - (1+r)^{b-1}}{(1+r)^n - 1}\right] = X - Y \qquad (3)$$

The application of the above formulas is shown in Tables 5 and 6. In Table 5 is shown the difference resulting from making a uniform annual payment of \$70.36 into a sinking fund throughout a period of 20 years, or of making an annual payment of \$50 into the sinking fund, to apply to the amortization of the loan (principal), and of an additional annual sum to cover the interest upon the outstanding bonds remaining, both figured for a 20-year loan of \$1 000 at a $3\frac{1}{2}\%$ rate. In Table 6 are shown substantially the annual payments required to meet principal and interest upon a \$1 000 000 and a \$5 000 000, 30-year loan bearing 4% interest. In both the latter cases it should be noted that the bonds must be paid off in amounts of \$1 000 each, and not in fractional parts thereof.

TABLE 5. Mr. Metcalf.

Consider an issue running 20 years at 3½%, the annual cost per $1 000 of the loan would be:

n Year.	Principal payment.	Interest payment.	Total payment.	Total payments when $50 and interest are paid each year.
1	$35.361	$35.00	$70.361	$85.00
2	36.598	33.763	70.361	83.25
3	37.880	32.481	70.361	81.50
4	39.206	31.155	70.361	79.75
5	40.578	29.783	70.361	78.00
6	41.998	28.363	70.361	76.25
7	43.468	26.893	70.361	74.50
8	44.989	25.372	70.361	72.75
9	46.564	23.797	70.361	71.00
10	48.193	22.168	70.361	69.25
11	49.880	20.481	70.361	67.50
12	51.626	18.735	70.361	65.75
13	53.433	16.928	70.361	64.00
14	55.303	15.058	70.361	62.25
15	57.239	13.122	70.361	60.50
16	59.242	11.119	70.361	58.75
17	61.315	9.046	70.361	57.00
18	63.462	6.899	70.361	55.25
19	65.683	4.678	70.361	53.50
20	67.982	2.379	70.361	51.75
Total.	$1 000.00	$407.220	$1 407.22	$1 367.50

A member of this Society has called the attention of the writer to a misstatement by him in his paragraph upon the "effort to eliminate, in water-works valuation, the value of franchise and other rights acquired by legislative grant," in his inclusion of Haverhill as one of the cases in which Massachusetts has sought to eliminate the element of franchise value in water-works valuation; has suggested that the action taken upon the Newburyport and Gloucester cases was a direct result of the exceedingly unfortunate and ill-advised attitude toward the public of the principal owner of these works, and of his failure to recognize what would to-day appear obvious obligations on the part of his corporations to furnish adequate and satisfactory service to these communities; and has expressed the opinion that it is at least open to doubt whether Massachusetts has in fact changed her policy upon this subject.

The writer accepts the correction in regard to the Haverhill case and the comments upon the Newburyport and Gloucester cases, but is still of the opinion that the recent legislation in Massachusetts bearing upon the formation and operation of water-works and other quasi-municipal corporations does justify his statement that the recent tendency has been to attempt to exclude the values growing out of franchise and future earning capacity in corporations of this character.

Mr. Metcalf. The writer is much pleased with the discussions of his paper and the new material which has been contributed.

In answer to Mr. Burns' comment that it is difficult to understand why the testimony, covering the cost to the consumer of serving himself by the substitution of another equally efficient, but different, structure to do the work of the existing plant, was not given consideration in the Portland case, in conformity with the rulings of the Maine Supreme Court, it may be said that the Maine courts have always ruled that the proceedings concerned an existing property and not some other property of equal efficiency which might be substituted for it, and hence that the testimony upon reproduction cost must be limited to the cost of reproducing the same structure and not another structure, even though of equal efficiency.

TABLE 6.—Thirty-Year Issue—Interest 4%.

n Year.	Principal payment. (Theoretical.)	Adjusted for Total Issue of:					
		$1 000 000.			$5 000 000.		
		Principal.	Interest.	Total.	Principal.	Interest.	Total.
1	$17.83	$18 000	$40 000	$58 000	$89 000	$200 000	$289 000
2	18.55	19 000	39 280	58 280	93 000	196 440	289 440
3	19.29	19 000	38 520	57 520	96 000	192 720	288 720
4	20.06	20 000	37 760	57 760	100 000	188 880	288 880
5	20.86	21 000	36 960	57 960	104 000	184 880	288 880
6	21.69	22 000	36 120	58 120	108 000	180 720	288 720
7	22.56	23 000	35 240	58 240	113 000	176 400	289 400
8	23.46	23 000	34 320	57 320	117 000	171 880	288 880
9	24.40	24 000	33 400	57 400	122 000	167 200	289 200
10	25.38	25 000	32 440	57 440	127 000	162 320	289 320
11	26.39	26 000	31 440	57 440	132 000	157 240	289 240
12	27.45	27 000	30 400	57 400	137 000	151 960	288 960
13	28.54	29 000	29 320	58 320	143 000	146 480	289 480
14	29.69	30 000	28 160	58 160	148 000	140 760	288 760
15	30.88	31 000	26 960	57 960	154 000	134 840	288 840
16	32.11	32 000	25 720	57 720	161 000	128 680	289 680
17	33.40	33 000	24 440	57 440	167 000	122 240	289 240
18	34.73	35 000	23 120	58 120	174 000	115 560	289 560
19	36.12	36 000	21 720	57 720	181 000	108 600	289 600
20	37.56	38 000	20 280	58 280	188 000	101 360	289 360
21	39.07	39 000	18 760	57 760	195 000	93 840	288 840
22	40.63	41 000	17 200	58 200	203 000	86 040	289 040
23	42.26	42 000	15 560	57 560	211 000	77 920	288 920
24	43.95	44 000	13 880	57 880	220 000	69 480	289 480
25	45.70	46 000	12 120	58 120	229 000	60 680	289 680
26	47.53	48 000	10 280	58 280	238 000	51 520	289 520
27	49.43	49 000	8 360	57 360	247 000	42 000	289 000
28	51.41	51 000	6 400	57 400	257 000	32 120	289 120
29	53.47	53 000	4 360	57 360	268 000	21 840	289 840
30	55.60	56 000	2 240	58 240	278 000	11 120	289 120
Total.	$1 000.00	$1 000 000	$734 760	$1 734 760	$5 000 000	$3 675 720	$8 675 720

Mr. Burns contends "that normal prices appear to be the proper basis of valuation to be used in fixing rates, but not so in the purchase of the property," and holds that "from the standpoint of the seller, there seems to be no reason in equity why the plant should be valued upon prices other than those in vogue at the immediate date of sale." Theoretically, the latter statement would seem to be sound, but, practically, the difficulty lies in the fact that the cash payment for the property is often not made until months after the date of valuation and taking, and prices may rise and fall within this interval in a way to work serious injury to one party or the other. As to the prices which should be used in figuring the reproduction cost, that is, whether these prices should be assumed as of the date of taking, or sufficiently in advance thereof to permit of the complete construction of the works on the date of taking, opinion seems to be divided, so far as the writer's experience goes. It is believed that both methods have been used in valuation cases in this country, the former upon the theory expounded by Mr. Burns, the latter upon the theory that, in order to deliver the works as of the date of taking, sufficient time must be given to build the works complete. The former view appears to be the more logical, but, in the Maine cases with which the writer has been familiar, the latter has always been the method used. Mr. Metcalf.

If "normal prices" are to be used as a basis for determining the reasonableness of the rates, it may well be asked why this same basis should not be used in the valuation of the property. To say that the loss due to the construction of works at a time of exceedingly high prices should fall upon the investor, without qualification, does not seem equitable or sound public policy, though the writer admits that it is perhaps a relative question how far one is justified in taking into consideration the conditions which existed at the time of the construction of the works. In fixing the rates, however, it appears reasonable to adjust the scale so as to permit the early liquidation of the excessive cost of works built in a period of high prices, provided the works were built in response to a definite need, and thus in effect reduce within a comparatively short time the outstanding capital to a point corresponding to or commensurate with normal or average prices. *Per contra,* if the works are built at a period of exceedingly low prices, it is not unreasonable to the owners of the property to assume that the water consumers should derive an advantage therefrom in the shape of lower rates.

As to the depreciation question—while awards have not usually been made in such detail as to permit one to judge whether or not proper allowance was made for this item—it has seemed to the writer in a number of instances that the high awards resulting have probably been due to failure to make such proper depreciation allowances. In this connection, the recent Supreme Court decision in Knoxville *vs.*

Mr. Metcalf. Knoxville Water Company is helpful, as it recognizes the necessity and propriety of allowing a reasonable annual allowance for depreciation to be carried by the rates, and it is to be assumed that it will be possible hereafter, in valuation, to obtain a better recognition of the loss in value due to depreciation.

The writer takes issue with Mr. Burns on his allowance for interest upon the sinking fund as compared with his rate of interest upon the capital. As a matter of fact, water companies usually reinvest their surplus funds in plant, and not in a sinking fund carried independently of the works, and this is good business policy, since a higher rate of interest can thus be obtained upon the sinking fund than would otherwise be possible. Under these circumstances, it is no more than fair to allow to the water company upon its sinking fund a rate of interest commensurate with that at which money is borrowed for its new construction. It certainly would not appear to be good policy, or indeed in the public interest, to require the water company to accumulate in the hands of an investing committee, or of some bank acting as trustee upon its securities, a sinking fund drawing a rate of interest of but $2\frac{1}{2}$ to 3%, as Mr. Burns suggests, and at the same time to go into the open market to raise money at 5 or 6% for its new work. The writer believes it to be wise, however, to permit the retiring of the bonded debt of the company by payment through sinking fund, when funds are available, and this method of operation will in effect result in increasing the rate of interest which would otherwise be obtained upon a sinking fund invested outside of the water-works or held in trust by some bank or trust company.

In comment upon Mr. Williams' interesting discussion, the writer understands that neither the Maine nor the Pennsylvania decision is predicated upon any difference in the character of the service to be furnished to the community.

The contention that the fire-protection service should bear its fair proportion of the cost of operation, maintenance, and fixed charges, is well taken. The writer believes it to be the fact, however unfortunate as it is, that the tendency is to reduce the hydrant rentals or other charges for fire protection to a point clearly far below the actual worth or cost of the service to the community, thus in effect increasing the burden to be carried by the consumers.

Upon Mr. Williams' obsolescence theory, it is perhaps only necessary to say that one deals with average conditions, generally, in any water-works valuation, and that the examples of non-obsolescence must be exceedingly rare. Even in the case cited, while some parts of the small cast-iron pipe system may continue to serve its use practically indefinitely, this assumption may involve the need of removing tubercles from the interior of the pipe by scraping, the cost of which operation would be included as an operating charge, and it is possible that

the time might come when the cost of repeated scrapings would be so great as to make it more economical to relay the pipe with new material with better coating. The point is a comparatively trivial one, however, in the broad consideration of the valuation of the works as a whole. Mr. Metcalf.

United States Supreme Court

Decision in the Case of Mayor and Aldermen of Knoxville *vs.* Knoxville Water Company, January 4th, 1909, Mr. Justice Moody.

Interference of Court.—Mr. Justice Moody holds that the court should hesitate to enjoin the enforcement of an ordinance reducing rates, except in extreme cases where confiscation would obviously result.

Rate-Making Function.—"Nevertheless the function of rate making is purely legislative in its character, and this is true whether it is exercised directly by the legislature itself or by some subordinate or administrative body, to whom the power of fixing rates in detail has been delegated. The completed act derives its authority from the legislature and must be regarded as an exercise of the legislative power." This seems to establish the doctrine that the rates of public service corporations may be regulated by City Governments under legislative authority, or duly empowered Public Service Commissions, as well as by the State Legislature under whose jurisdiction the public service corporation is operated.

Capitalization of No Significance.—"Counsel for the company urge rather faintly that the capitalization of the company ought to have some influence on the cost in determining the valuation of the property. It is a sufficient answer to this contention that the capitalization is shown to be considerably in excess of any valuation testified to by any witness, or which can be arrived at by any process of reasoning."

Depreciation.—"It was urgently contended that in fixing on the value of the plant upon which the Company was entitled to earn a reasonable return, the amounts of complete and incomplete depreciation should be added to the present value of the surviving parts. The Court [Lower Court] refused to approve this method, and we think properly refused * * *.

"The Company is not bound to see its property waste without making provision out of earnings for its replacement. It is entitled to see that from earnings the value of the property invested is kept unimpaired, so that at the end of any given term of years the original investment remains as it was at the beginning. It is not only the right of the Company to make such a provision, but it is its duty to its bond- and stock-holders, and in the case of a public servive corporation, at least, its plain duty to the public * * *.

"If, however, a company fails to perform this plain duty and to exact sufficient returns to keep the investment unimpaired, whether this is the result of unwarranted dividends upon over-issues of securities, or of omission to exact proper prices for the output, the fault is its own. When, therefore, a public regulation of its prices comes under this question, the true value of the property then employed for

Mr. Metcalf. the purposes of earning a return cannot be enhanced by a consideration of the errors which have been committed in the past."

It is to be hoped that the use of the word "error," by Justice Moody, is significant, and that it implies a recognition of the right of a corporation in the years following upon the early years of loss in operation during the formative period, to make good through the agency of the rates such early losses, unless these have been wanton and incurred without a due consideration of the public interest and ultimate benefit.

Discount at Expense of Company.—Justice Moody calls attention to the fact that the discount for prompt payment of bills in cash was made at the option of the Company and not required by ordinance, though it is but fair to add that he recognizes that failure to make this allowance would somewhat increase the cost of collections.

Fair Return or Reasonable Rate of Interest upon Value.—As bearing upon the case at bar, Justice Moody said: "The net income in any event would be substantially 6%, or 4% after an allowance of 2% for depreciation. One cannot know clearly that the revenue would not much exceed that return. We do not feel called upon to determine whether a demonstrated reduction to that point would or would not amount to confiscation."

It appears unfortunate that Justice Moody did not express an opinion upon this point, as did Justice Peckham in the Consolidated Gas Company case hereinafter quoted. In the light of the latter's ruling, 4% exclusive of depreciation would appear obviously to be an inadequate return upon this or any water-works property, and thus make the ordinance confiscatory in its application. It is also worthy of note here that Justice Peckham's comment in the Consolidated Gas Company case upon the probable effect of the reduction in rates in increasing the consumption of gas, and hence the revenue from its sale (as it is reasonable to assume that many additional consumers might be obtained under reduced rates, since several good substitutes for gas are always available to consumers) does not apply with equal force to water, which is a public necessity, except, perhaps, in rural communities where water may readily be obtained from wells or other individual sources.

Inclusion of Data Acquired Subsequent to Bringing Suit.—The Supreme Court held that inasmuch as the precise subject of inquiry was, what would be the effect of an ordinance in the future, "* * * evidence of the operations of the years subsequent to the ordinance is relevant and of great importance, and by a consideration of such evidence a much greater increase of certainty could be obtained."

Inclusion of Going Concern Element in Value.—Although the fact does not appear in the dictum of the Supreme Court, the value of the property to which the fair rate of return is to be applied included an allowance, made by the Master and approved by the Lower Court, covering "going concern value." It is also but fair to add that no claim

was made by the Water Company for "franchise value," except such as was included in the valuation of the plant, upon which the Consolidation ordinance of 1899 of the City of Knoxville, hereafter referred to, was predicated. Mr. Metcalf.

UNITED STATES SUPREME COURT.

Willcox *vs.* Consolidated Gas Co.

January 4th, 1909, Mr. Justice Peckham.

Statement.—"Prior to 1884, there were seven Gas Light Companies in New York, each operated under separate charters granted at different times between the years 1823 and 1865 or 1871. They each had the right to use the streets of certain portions of the city, for the purpose of laying their mains and service pipes, in order to furnish gas to the city and to the citizens. Not one of the companies had ever been called upon to pay a penny for such right, but the grant to each was in that aspect a gratuity. It was not, at the time of granting franchises such as these, the custom to pay for them. In 1884, by Chapter 367 of the laws of that year, authority to consolidate manufacturing corporations was granted upon conditions mentioned in the act."

Interference by Court.—Justice Peckham takes the same ground as Justice Moody, in the Knoxville Water Company case, on this subject —that "the case must be a clear one before the Courts ought to be asked to interfere with State Legislation upon the subject of rates, especially before there has been any actual experience of the practical result of such rates."

Uncertainty as to the Effect of Ordinance upon Rates.—The Court calls attention to the fact that where the valuation of the plant is so much a matter of opinion, the effect of slight change in this valuation may be material in its effect upon the earnings, and hence rates, and furthermore that the decrease in the rates might result in materially increasing earnings, owing to greater consumption under smaller rates.

State Franchise Value for Taxation Not a Criterion of Value.— "The complainant also contends that the State having taxed it upon its franchises, cannot be heard to deny their existence or their value as taxed.

"The fact that the State has taxed the company upon its franchises at a greater value than is awarded them here, is not material. * * * Those taxes were properly treated by the company as part of its operating expenses, to be paid out of its earnings before the net amount could be arrived at applicable to dividends, and if such latter sums were not sufficient to permit a proper return on the property held by the company for the public, then the rate would be inadequate. The future assessment of the value of the franchises, it is presumed, will be much lessened, if it is seen that the great profits upon which that value was based are largely reduced by legislative action * * *."

Franchise Value.—As this question is so wrapped up in the consideration as to the weight which should attach in rating cases to previous valuations, legislation, or litigation, Mr. Justice Peckham's opinion upon this point has been quoted at some length.

"The Court [Circuit Court] further stated that it 'does not

Mr. Metcalf. appear in the evidence how the valuation of the franchises was measured, or why the figures selected were chosen, but it was true that when the complainant was organized in 1884, under the consolidation statute, which in terms permitted it to acquire the property and franchises of other companies, it issued stock of the par value of $7 781 000, representing the franchises it then acquired and nothing else, and that the stock was held by purchasers who, I am legally compelled to think, had a right to rely upon legal protection for legally issued stock. * * * The result was that the amount of the stock issued by the Consolidated Company was increased by $7 781 000, representing a value of franchise which was agreed upon by the stockholders in the companies, and which had never cost any of them a single penny. It cannot be disputed that franchises of this nature are property, and cannot be taken or issued by others without compensation. * * * The important question is always one of value. * * * The trial court said * * * 'It appears to me that a fair method of fixing value of the franchises in 1905 is to assume the same growth in value for the franchises as is demonstrated by the evidence in the case of tangible property. * * * This, I think, is a logical result from the assumption I am compelled to start with, *i. e.,* that franchises have a separate and independent value. But there is, however, no method of valuing franchises, except by a consideration of earnings; earnings must be proportioned to assets; and both kinds of assets, tangible and intangible, must stand on the same plane of valuation; having, therefore, a measure of growth of tangible assets from 1884 to 1905, the franchise assets must be assumed to have grown in the same proportion.' * * *

"We are not prepared to hold with the court below as to the increased value which it attributes to the franchises. It is not only too much a matter of pure speculation, but we think it is also opposed to the principle upon which such valuation should be made. This corporation is one of that class which is subject to regulation by the legislature in the matter of rates, provided they are not made so low as to be confiscatory. The franchise granted the various companies and held by the complainant, consisted in rights to open the streets of the city and lay down mains and use them to supply gas, subject to legislative right to so regulate the price for the gas as to permit not more than a fair return upon the reasonable value of the property at the time it is being used for the public."

Effect of Previous Legislation or Litigation upon Valuation.—"The Senate Committee appointed in 1885 to investigate the facts surrounding the consolidation said The Gas Companies had an agreement among themselves fixing the price of gas at a figure that paid these dividends. The people were paying this price as they had in the past without objection or protest. This price may have been high and dividends were excessive, but they were not illegal, and the valuation of the franchises computed upon these dividends and that state of facts cannot be called a violation of a law that expressly authorizes it to be done, unless such valuation was too high.

"Assuming as the Committee did that the Company would be permitted to charge the same prices in the future which in the past had resulted in these 'enormous' or 'excessive' dividends, it need not be a

matter of surprise that a franchise by means of which such dividends had been possible was not regarded as over-valued at the sum stated in 1884. Mr. Metcalf.

"We think that under the above facts the courts ought to accept the valuation of the franchises fixed and agreed upon under the Act of 1884 as conclusive at that time. The valuation was provided for in the Act, which was followed by the Companies, and the agreement regarding it has been always recognized as valid and the stock has been largely dealt in for more than twenty years past, on the basis of the validity of the valuation, and of the stock issued by the company. * * * We do not think that an increase in that valuation ought to be allowed upon the theory suggested by the court below. Because the amount of gas supplied has increased to the extent stated, and the other and tangible property of the corporations has increased so largely in value, is not, as it seems to us, any reason for attributing a like proportional increase in the value of the franchise. * * * Its past value was founded upon the opportunity of obtaining these enormous and excessive returns upon the property of the company without legislative interference with the price for the supply of gas, but that immunity for the future was, of course, uncertain, and the moment it ceased and the legislature reduced the earnings to a reasonable sum, the great value of the franchise would be at once and unfavorably affected, but how much so it is not possible for us now to see. * * *

"What has been said herein regarding the value of the franchise in this case, has been necessarily founded upon its own peculiar facts, and the decision thereon can form no precedent in regard to the valuation of franchises generally where the facts are not similar to those in the case before us. We simply accept the sum named as the value under the circumstances stated."

Good-Will and Monopoly Value.—"We are also of the opinion that it is not a case for a valuation of 'good-will.' The master combined the franchise value with that of good-will and estimated the total value at $20 000 000.

"The complainant has a monopoly in fact and the consumer must take gas from it or go without. He will resort to the old stand because he cannot get gas anywhere else. The court below excluded that item and we concur in that action."

On the other hand, the Court, as appears above, did allow the valuation of the franchise as of the earlier date of consolidation of the several gas companies under legislative authority.

Fair Return or Reasonable Rate of Interest upon Value.—"There is no particular rate of compensation which must in all cases and in all parts of the country be regarded as sufficient for capital invested in business enterprises. Such compensation must depend greatly upon circumstances and locality * * * the amount of risk * * * locality where the business is conducted, and the rate expected and usually realized there upon investments of a somewhat similar nature, with regard to the risk attending them.

"In an investment in a gas company, such as complainants', the risk is reduced almost to a minimum. It is a corporation which, in

Mr. Metcalf. fact, as the court below remarks, monopolizes the gas service of the largest city in America and is secure against competition under the circumstances in which it is placed, because it is a proposition almost unthinkable that the city of New York would, for purposes of making competition, permit the streets of the city to be again torn up, in order to allow the mains of another company to be laid all through them to supply gas which the present company can adequately supply. * * * It seems as certain as anything that the demand for gas will increase and at the reduced price increase to a considerable extent. * * * The court held that the rate which would permit a return of 6% would be enough to avoid a charge of confiscation. * * * We concur with the court below on this question and think complainant is entitled to 6% on the fair value of its property devoted to the public use."

Note that, while no specific reference is made herein to an allowance for depreciation, the Knoxville opinion, which immediately preceded this, clearly holds that a suitable allowance for depreciation is a proper and necessary operating charge, and it is therefore to be inferred that Mr. Justice Peckham had in mind, as a reasonable return upon this property, a 6% rate in excess of an allowance for depreciation. Any doubt upon this point is precluded by the fact that in the testimony, approved by the Lower Court and upon which the Supreme Court based its findings, allowance was actually made for depreciation as an annual operating charge from which the earnings of the company were figured. It is most unfortunate, however, that the words of the Supreme Court should not have made this fact clear.

Valuation as of Date of Taking.—"The value of the property is to be determined as of the time when the inquiry is made regarding the rates. If the property which legally enters into the consideration of the question of rates has increased in value since it was acquired, the company is entitled to the benefit of such increase."

Pressure and Penalty Provisions Void.—As to the gas pressure requirements of the ordinance, the Court admits that they would involve heavy capital expenditures without increase in income and that * * * "This would take from the complainant the ability to secure the return to which it is entitled upon its property, used for supplying gas, and the provision as to the amount of pressure is therefore void. * * * If these provisions as to penalties have been properly construed by the court below, they are undoubtedly void because so enormous and overwhelming in their amount."

Illegality of Part of Statute Does Not Affect Legality of the Rest.—"When the objectionable part of the statute is eliminated, if the balance is valid and capable of being carried out, and if the court can conclude it would have been enacted if that portion which is illegal had been omitted, the remainder of the statute thus treated is good * * *."

Opinion of Lower Court Reversed.—"Upon a careful consideration of the case before us, we are of the opinion that the complainant has failed to sustain the burden cast upon it of showing beyond any just or fair doubt that the acts of the Legislature of the State of New York are in fact confiscatory.

"It may possibly be, however, that a practical experience of the

effect of the acts by actual operation under them might prevent the complainant from obtaining a fair return, as already described, and in that event complainant ought to have the opportunity of again presenting its case to the court. To that end, we reverse the decree, with directions to dismiss the bill without prejudice, and it is so ordered." Mr. Metcalf.

The Gas Company's petition for a rehearing before the U. S. Supreme Court was denied.

As the opinion of Justice Moody in the Knoxville Water Company case seemed to be in conflict with the ruling of Justice Peckham in the Consolidated Gas Company case upon the vital consideration as to whether or not the results of previous legislative enactment or litigation should furnish a basis or starting point for the future determination of the value of the property (upon which any consideration of the reasonableness of the rates should be predicated), the Knoxville Water Company (as did the Consolidated Gas Company before it) petitioned for a rehearing of its case.

In order to make clear some points in the opinion of Justice Moody, and the grounds of the Water Company for desiring a reopening of its case, it may be of interest and advantage to outline briefly the situation leading up to this litigation and recent decision of the Supreme Court of the United States.

In the year 1890, the present owners of the Knoxville Water Company purchased a controlling interest in the Company—the plant of which then supplied the original City of Knoxville, under contract with the city dated July 1st, 1882. In 1891, contract was made by the same parties, though not by the Knoxville Water Company, to furnish North Knoxville with a water supply, and the works built for this purpose were sold to the Knoxville Water Company in 1893. In the meantime, the town of West Knoxville had entered into contract, under date 1892, with a local concern, the Lonsdale-Beaumont Water Company, for a water supply. Later, the Lonsdale-Beaumont Company desired to consolidate its works with those of the Knoxville Water Company, but this was impossible under the Tennessee Act of 1889, which expressly forbade such consolidation of public service corporations, without the express written approval and consent of the municipal government. In 1899 the City of Knoxville passed an ordinance giving its consent and approval (upon certain terms which included the furnishing of filtered water to the entire city and the right of the city to purchase the works of the company) to the desired consolidation of the Lonsdale-Beaumont Water Company with the Knoxville Water Company, required the Knoxville Water Company to guarantee the existing debts of the consolidated companies, and granted to it the right to issue bonds to the extent of not exceeding $800 000 prior to the first of January, 1901, for this purpose, and to issue further bonds to provide funds for future additions or improvements, requiring the cost of these additions or improvements to be certified to the recorder

Mr. Metcalf. of the city in a sworn statement. Specific rates for water service were also prescribed, and these rates have been substantially adhered to by the Company up to the present time.

The rate question soon became a political issue, and various abortive attempts were made to reduce the rates, and resulted finally in the rate ordinance of March 30th, 1901, the subject of the present litigation. The Mayor, elected upon an anti-water-company platform, in a message to the City Council, called attention to the fact that, though the City had been unable to obtain full information from the Water Company, the city could only lose its rates-regulating case on the ground of its confiscatory nature, in which event it could still recover much more than the cost of litigation through increase in taxation of the company's property—upon the valuation placed upon it by the company itself or developed in the litigation. The shrewdness and soundness of the Mayor's position has since been shown, as will be seen.

Shortly after the passage of the rate ordinance of March 30th, 1901, the Water Company brought two actions against the city, in its attempt to prevent the reopening of the rate issue. The first of these suits was brought on the ground that the action of the city was in contravention of its contract with the Water Company, and this suit went up to the United States Supreme Court, which, through Mr. Justice Holmes, in 189 U. S., 444, handed down a decision to the effect that nothing in the contract prevented a revision of the rates within reasonable limits, although the Water Company was then charging slightly less than the specific rates embodied in the contract of 1899 with the city. The second suit, which followed shortly thereafter, sought to enjoin, through the United States Circuit Court, the enforcement of the new rate schedule, on the ground of its unreasonableness. A Master was appointed to take evidence, and the hearings began in November, 1902. In August, 1904, the Master's decision, favorable to the Water Company, was handed down, and was substantially affirmed a few months later by the Circuit Court. On January 21st, 1907, the city appealed to the United States Supreme Court, which handed down, on January 4th, 1909, the opinion of Mr. Justice Moody quoted herein, which reversed the decision of the lower Court without prejudice, and in substance required the Company to accept the rates established by the ordinance of 1901, subject to the Company's right to bring suit hereafter upon the ground of the confiscatory nature of the rates, should actual experience with the rates prove them to be of such a character.

In the meantime, the city found other means of reaching the Water Company more directly, for in 1903 authority was obtained from the Legislature to purchase the works of the Water Company on agreement or appraisal, and to issue bonds in payment therefor, or, in case it should be unable to obtain a satisfactory price from the Water

Company, to submit to referendum vote the question as to whether the city would build competing works; and, simultaneously, the valuation of the Company's plant was raised 50% for purposes of taxation. A year later, on failure to obtain a satisfactory price on its property from the Water Company, the city voted to issue $750 000 of bonds and build competing works, in spite of the express contract provisions requiring the purchase of the existing works from the Water Company by arbitration. Concurrently, the Water Company enjoined the city from building competing works, on the ground of existing contracts between it and the city, through the agency of the United States Circuit Court. This resulted in an appealed decision, handed down by the United States Supreme Court, in which it was held, on January 2d, 1906, by Mr. Justice Harlan (200 U. S., 22) that: "The City of Knoxville cannot be held to have precluded itself by contract from establishing its own independent system of water-works," inasmuch as there was no express stipulation in the contract forbidding the city to construct a plant for itself supplying the city and its inhabitants with water, even though this restraint may have been implied in the contract by the fact that the city had agreed that it would not for the thirty-year period of the contract grant to any other person or corporation the same privileges which it had granted to this Water Company. That the question was not free from doubt is indicated by the dissent of four of the Justices from the opinion. In the following year, 1907, the valuation of the Company's plant for purposes of taxation was raised to 145% of the amount of the year 1901, or about 32% over the taxation of the previous year, though the earnings had increased but 57% and 11%, respectively. Mr. Metcalf.

Thus, since the vote of 1904, followed by the Supreme Court decision of 1906, the city has had the right to issue $750 000 of bonds to build competing works, and it has in fact had plans and specifications prepared, has advertised and had contracts let for this work, but it has not been able to market its bonds as yet. It should be added, however, that the city has made no active effort to market its bonds within the past year or more, though repeated efforts were made before this interval.

In the light of these facts, and the ruling of Justice Peckham in the Consolidated Gas Company case, in which he clearly held that the legislative enactment in regard to the franchise value of the existing plant as of a certain date must weigh in a determination or consideration of the value of the plant, and hence of the reasonableness of the rates, it is not surprising that the Water Company should have asked for a rehearing in appeal from the decision of Mr. Justice Moody, who practically ignored or gave no weight to the recognition by the City of Knoxville, in the consolidation ordinance of 1899, of the then value of the plant of the Water Company, amounting to $800 000,

Mr. Metcalf. which was further sustained by undisputed testimony in the suit showing an indebtedness of the Consolidated Companies amounting to $824 000, as of that date (in excess of the common stock of the companies).

The position of the Water Company is summed up in the following extract from its brief accompanying its petition for a rehearing before the United States Supreme Court:

"The city, instead of not being a party to the contract where the valuation of $800 000 was recognized, as was the case of the State in the Consolidated Gas Company case, was a party to said contract, and itself authorized in effect that valuation to be fixed as a basis of the issuance of securities to fund the indebtedness then existing. * * * An agreement was made between the regulating power—the city—and the Company, which it seems to us gives it much greater force and effect, and it is reasonable to suppose, as is supposed by the Court in the Consolidated Gas Company case, that this indebtedness and these securities of the Knoxville Water Company issued or funded, or authorized to be funded, by the issuance of bonds and stock of the Company, has been dealt in since 1889 by various parties, upon the faith of that agreement, and it will be noted that no limitation in time is placed upon the issuance of $800 000 of bonds for the purpose of taking up this indebtedness * * *."

In passing, it is also fair to add that the Company, in its petition, calls attention to the fact that Justice Moody's ruling, that a company may not hope to recover in later years for its failure to collect adequate rates in previous years, has no force in the present litigation, inasmuch as the Water Company has in fact continued to charge substantially all that it had been permitted to charge under the consolidation ordinance of 1899, and previous ordinances, excepting only some portions of the discount for cash.

The petition for rehearing has just been denied by the Supreme Court.

It is unfortunate that the Court has made no recommendation in regard to the method of meeting the cost of experimentation with rate ordinances, the loss resulting from operating under rates which shall prove confiscatory, and the cost of litigation in connection therewith, in view of its declaration that municipalities may at any time regulate the rates regardless of existing contracts, and that no Court should intervene by injunction, except in cases of an obviously confiscatory nature. It would seem equitable and highly desirable, from the point of view of sound public policy, to provide, in case of rate reduction, that the savings resulting from the enforced reduction in rates should be temporarily lodged with the Court, and that in cases where loss would result to the water companies, the sums accruing from the cut in the rates should be refunded to the company, and the cost of the experimentation devolve upon the municipality, or the water con-

sumers, and that the governing Court should so provide. Otherwise, public service corporations appear to have no redress from repeated reduction of rates, and the expensive litigation incident to the determination of their propriety. The effect of such a situation must inevitably be to discourage investment in quasi-municipal corporation enterprises and to retard wholesome growth and development, to the detriment of the community. Mr. Metcalf.

One cannot but feel that in handing down these two conflicting opinions, upon the Knoxville Water Company and the Consolidated Gas Company cases, and in failing to prevent ambiguity by clearly stating certain essential findings of the Lower Court upon which these opinions are based (as in the Consolidated Gas Company case, in which the 6% reasonable return is in excess of depreciation—which was specifically allowed by the Court below as a legitimate expense of operation—although this fact unfortunately does not appear in the Supreme Court's dictum), the Supreme Court of the United States has missed a splendid opportunity to clarify the atmosphere enshrouding the rating question, as applied to public service corporations.

Great uncertainty still exists in financial circles as to the probable final attitude of the Court upon some of the important questions involved in these cases—questions upon which the Court has just declined to rule, or upon which it has expressed opinions ambiguous at least, if not actually at variance with its preliminary declaration or preamble of governing principles. In other words, the Court's application of principles, in the Knoxville case particularly, seems to be at variance with its exposition of them. It may well be doubted, therefore, whether the Supreme Court has done much more in these two cases than to make clear to the public that the Courts will not enjoin the enforcement of rates-regulating legislation, except in cases of obviously confiscatory nature. Furthermore the Court has not prescribed methods of procedure which will safeguard the interests of the corporation whose fate is at bar, in case the revised rates do prove confiscatory. It does not seem possible that this can be the ultimate position of the Supreme Court of the United States.

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TRANSACTIONS

Paper No. 1106

THE PURIFICATION OF GROUND-WATERS CONTAINING IRON AND MANGANESE.*

By Robert Spurr Weston, Assoc. M. Am. Soc. C. E.

With Discussion by Messrs. W. C. Lounsbury, Arthur L. Terry, Jr., Philip Burgess, A. Elliott Kimberly, Alexander Potter, H. F. Dunham, E. Kuichling, J. W. Ellms, Langdon Pearse, and Robert Spurr Weston.

Introduction.

The primary source of ground-water is the moisture in the air. A part of this moisture, which precipitates as rain, snow, or dew, soaks into the ground until it reaches an impenetrable stratum where it collects in greater or less amount and is called ground-water. The soil air also contains moisture, a part of which condenses beneath the surface. Although Aristotle considered the mountains of the earth as sponges,† whose interstices collected the rain which appeared later in springs and wells, the present theory of the circulation of meteoric water is comparatively modern. Even as late as the middle of the seventeenth century, many of the philosophers believed that the source of ground-water was the water of the sea and of rivers which, soaking into the lower strata of the earth, was evaporated and then condensed nearer the surface.

The term "ground-water" comprises spring water and water from shallow, deep, and Artesian wells. From an engineering standpoint,

* Presented at the meeting of February 3d, 1909.

† F. R. Koenig, *Schillings Journal für Gasbeleuchtung und Wasserversorgung*, 49, 1033.

these waters differ in their hydrology only. They have the same primary source, and their physical and chemical characteristics differ in degree rather than in kind.

In the literature of the most ancient historic peoples there is frequent commendation of ground-water. It was especially attractive to those living in warm climates. Ground-water, especially flowing well water, "fountain of living water," was used frequently as a metaphor for expressing excellence; likewise, the modern conception of a satisfactory supply is best illustrated by a good ground-water, that is, one which is perfect in appearance, agreeable to the taste, soft, and bacteria-free. Furthermore, the object of all schemes for supplying water from other sources is to approach the characteristics of such a ground-water as nearly as practicable. Such waters as the Alpine supplies of certain European cities and the well-water supplies of a few New England and Atlantic Coast towns are good examples of this kind of water, of what from a laboratory standpoint is "pure spring water," the popular standard of excellence.

It is quite unnecessary to call to mind how satisfactory are such supplies. The examples are numerous, especially in Europe, and communities supplied with such waters are unusually free from epidemics of water-borne diseases. In Leipsic, for example, it is said that surgeons when performing operations use water direct from the tap as they would sterilized water.

Most of the best of the large water supplies in the United States have been from upland surface sources, but the increase in population on the catchment areas is imposing such additional burdens on methods of purification, whether they be storage in reservoirs or filtration, that water which by comparison does not have to be treated to protect consumers against the effects of pollution, is held in greater favor.

In many American cities the water consumption is excessive, and in some it has already become a problem where to go for additional surface supplies to meet the increasing demand. Again, supplies which were once satisfactory must now be purified to protect them against chance contamination by a rapidly increasing population. All these factors tend to cause a favorable consideration of ground-water sources.

In the early days of the United States, well-water supplies were very much used, but later, when larger supplies were necessary, the

wells were forgotten. A similar condition prevailed in Germany. Herr A. Thiem* believed that the example of England, foremost in sanitary matters twenty years ago, who devoted her energies to improving and storing surface water, greatly promoted the development of surface-water supplies. These supplies were comparatively "easy to obtain." They were not dependent upon speculation, deduction or induction; they required only a small knowledge of geology or hydrology; they involved little more than pure problems of construction, and for these reasons were not difficult. The water was not hard, and very often pumping was unnecessary.

The success of the Altona filters during the cholera epidemic of 1893 inspired great confidence in filtered surface supplies, and many were introduced into European cities. They have operated efficiently and economically in most cases, and have effected a great saving of life. At the same time there has been a parallel development of the abundant ground-water supply of Northern Germany and Holland, which is a much more acceptable drinking water than a surface water on account of the greater insurance against accidental pollution due to careless filtration or to accidental mixing of highly polluted unfiltered water with the filter effluent. Several of these accidental interruptions in filter operations have occurred during the past ten years, particularly in Altona in 1886, 1887, 1888, 1891, and 1892; in Berlin in 1889 and in Hamburg quite recently. Professor Bernard Fischer* believes that this cause of epidemics is anything but rare.

At present what may be called the ground-water movement is very strong in Germany. It is favored among others by such hygienists as Flügge, Fischer, and Dunbar, and by such engineers as Thiem, Anklam, Lindley, and Grahn, and the general trend is toward the use of such supplies wherever possible. While the German hygienists make rather extravagant claims for the sanitary inviolability of such supplies and for the protection afforded to strata of water-bearing gravel by thin layers of overlying silt and clay, still, as a rule, the supplies are excellent. They are usually moderately hard, but after the removal of iron and manganese and the small amount of hydrogen sulphide which they may contain, they are of excellent appearance, cool, and safe. The faults of surface supplies, namely, changing temperature, color,

* *Deutsche Vierteljahresschrift für öffentliche Gesundheitspflege*, 29, Heft 1.

odor, first cost, and possibility of contamination, have also caused the development of many so-called gravity "spring-water" supplies. Many European cities, Vienna and Naples, for example, which are near the mountains, are supplied in this way, likewise many mountain towns and villages.

In North America few large cities have been supplied with soft ground-water, and, while Indianapolis, Memphis, and Havana have ground-water supplies which are moderately hard, Brooklyn, Camden, Lowell, Newton, and Pueblo (Colo.), are about the only large cities which have soft ground-water supplies. In Europe many of the largest cities, for example, Budapest, Munich, Dresden, Leipsic, Amsterdam, Brussels, etc., have moderately hard ground-water supplies; Breslau, Berlin, and Hamburg, comprising a population of more than 3 500 000, are abandoning their filtered surface-water in favor of ground-water.

One reason for the paucity of ground-water supplies is the lack of knowledge, on the part of engineers and others, of the geology and hydrology of the subterranean sources. However, great progress has been made in late years; there is more ground-water existent than was generally supposed. It is present not only in the alluvium, but in some porous rocks, such as the Potsdam sandstone. It is believed by the writer that a thorough preliminary study of water problems would reveal, in many cases, satisfactory ground-water sources. Such studies, however, should be carried on by one acquainted with hydrological methods. Often, when true ground-water cannot be obtained, it may be practicable to supply consumers with artificial ground-water obtained by irrigating sandy tracts with surface-water and collecting the water from the same by suitable wells or collecting galleries.

In Germany the cost of supplying a ground-water, deferrization included, is usually less than that of a filtered surface-water. This is because higher rates of filtration may be used and also because the cost of operating the filters is less.

In his study of the Breslau supply, Herr A. Thiem compared the costs as shown on Fig. 1.

The advantages of a good ground-water over a filtered surface-water supply may be summarized as follows:

1.—Absence of color, odor, and objectionable taste.

2.—Safety.

3.—Small seasonal variation in temperature.

4.—Lower cost.

5.—Less danger from frost.

All ground-waters are not satisfactory. Those which are too hard or too alkaline and those which contain more than small amounts of chlorides or traces of iron or manganese are unfit to use in their unpurified condition. This paper does not concern itself with methods of water-softening or alkali reduction, but with the theory and prac-

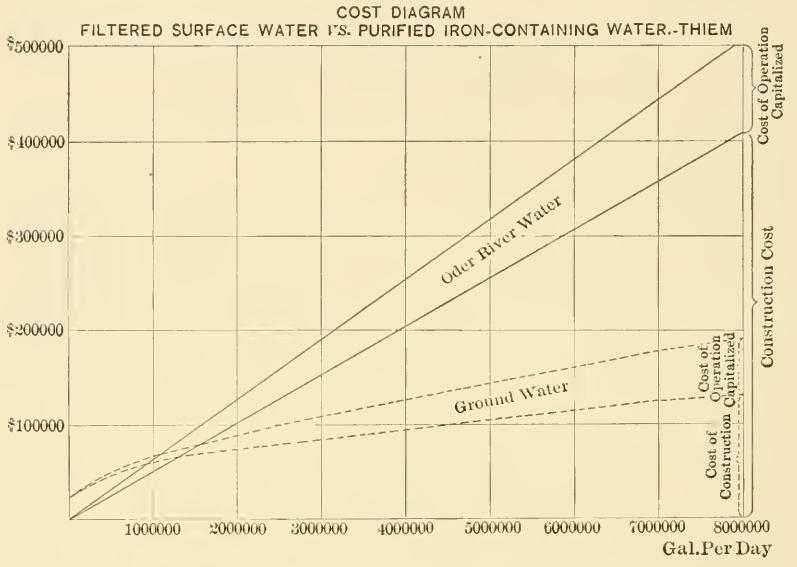

Fig. 1.

tice of the iron-removal processes in use in Europe and America. In Germany, Herr A. Thiem has coined the word *Enteisenung* to describe the iron-removal process. The new Technological Dictionary will give "deferrization" as the translation of this word, which means literally "taking of iron away from" (water). Likewise one might use demanganization to describe the removal of manganese.

The deferrization and demanganization of ground-waters will be discussed under the heads: Theoretical; Historical; European Practice; Experience at Reading, Mass., and other American Water-Works; Demanganization; Design of Deferrization Plants; and Conclusion.

Theoretical.

Characteristics of Typical Iron-Containing Waters.

When typical ground-waters containing iron are freshly drawn, they are clear and colorless or nearly so, contain high amounts of carbon dioxide, sometimes considerable methane or hydrogen sulphide, and are deficient in oxygen. They have the styptic or "inky" taste which is characteristic of iron. When sufficient oxygen has had access to the water, it becomes turbid with oxidized insoluble iron, which after a shorter or longer time gathers into flocs and finally precipitates, leaving the water itself colorless and free from iron. Where there is no purification plant, this precipitation takes place in the distribution system; tea made with the water is black; rust spots appear on linen, and white plumbing fixtures are stained with iron rust. After a sudden disturbance, as after a large fire, the water is exceedingly turbid with precipitated iron oxide. In some cases a fungus, *Crenothrix*,* grows in the pipes, feeding upon the organic matter and causing a precipitation of the iron contained in the water. Frequently the growth of this organism chokes service pipes and small mains, while the odors due to its death and decomposition become extremely disagreeable.

Manganese-containing waters have similar characteristics, except that the precipitation is slower and the stains and deposits are much darker in color. Certain ground-waters contain a little alumina, which behaves in much the same way, but, because the precipitate is white, it has never been known to cause trouble, although it is known to accompany the growth of *Crenothrix ochracea*.†

Character of Ground-Water.

Like other natural products, ground-water containing iron and manganese varies greatly in its composition, as shown in Table 1.

The primary sources of iron in ground-water are the deposits of iron in the earth's crust, amounting, according to Mr. F. W. Clark,‡ to 5.46%, that is, the fourth in importance of the elements composing the earth. The solvent of the iron is the ground-water itself, aided by the acids dissolved in it. It has been stated by many writers, and it is quite commonly believed, that iron exists in water as a salt of one or more of the acids, chiefly as ferrous carbonate; but Whitney§

* D. D. Jackson, *Journal*, Society of Chemical Industry, 21, 681.
† D. D. Jackson, *Transactions*, Am. Micros. Soc., Vol. XXIII, p. 32.
‡ Chemist, U. S. Geological Survey.
§ "The Corrosion of Iron," *Journal*, Am. Chem. Soc., 25, 394.

TABLE 1.—Composition of Ground-Waters Containing Iron and Manganese.

(Parts per Million.)

Locality.	Worms.	Berlin, Müggelsee.	Posen, Shallow well.	Posen, Deep well.	Lowell, Mass.	Reading, Mass., Nov., 1891.	Reading, Mass., Jan., 1900.	Reading, Mass., June, 1902.	Provincetown, Mass., Average.	Marblehead, Mass., Average.	New Orleans, La., Deep well.	New Iberia, La., Deep well.
Color	.....	.....	100–	1 000 +	8.	4.	39.	105.	92.	7.	1 400.	11.
Temperature, in degrees centigrade	9.4	10.	.... .	.....	.....	.....	.....	.....	.....	.....	.....	.....
Iron	19.5	1.12	12.	0.6	3.1	13.3	3.9	1.4	3.6	1.	3.2	8.6
Manganese	.....	.....	1.2	0.0	.....	.....	.....	.....	.....	.....	.....	.....
Oxygen consumed	1.3	3.9	24.	246.	0.7	.....	3.3	7.4	7.1	0.4	14.3	3.0
Free ammonia	0.0	0.280	0.7	2.6	0.080	0.008	0.110	0.088	0.124	0.065	0.029	3.3
Alb. ammonia	.....	.....	.....	.....	0.031	0.270	0.064	0.132	0.183	0.022	0.181	0.09
Nitrites	0.0	0.000	0.00	0.00	0.001	0.001	0.001	0.001	0.001	0.002	0.400	0.00
Nitrates	trace	0.0	0.0	0.0	0.242	0.20	0.04	0.06	0.055	0.61	0.00	0.00
Chlorine	24.	5.6	18.	178.	2.7	4.2	5.4	4.1	2.6	29.5	.....	10.5
Total hardness	.....	166.	272.	160.	18.	116.	33.	31.	25.	75.	403.*	430.*
Residue on evaporation	350.	242.	464.	645.	44.	264.	96.	75.	105.	174.	857.	500.
Calcium, Ca	158.	.....	88.	43.	.....	.....	.....	.....	.....	.....	.....	.....
Magnesium, Mg	.....	.....	13.	12.	.....	.....	.....	.....	.....	.....	.....	.....
Sulphuric acid, SO_4	.....	20.	47.	37.	.....	.....	.....	.....	.....	.....	.....	.....
Free carbon dioxide	.....	.....	16.	46.+	.....	.....	.....	.....	.....	.....	.....	.....
Hydrogen sulphide	Present	Present	Present	0.	.....	Present	Present	Present	Present	.....	.....	.....

* Alkalinity (Na_2CO_3). + Total carbon dioxide.

has proved that absolutely pure water, free from oxygen and carbonic acid, will dissolve an appreciable amount of metallic iron. The force which causes this solution (the "solution pressure") is an electrical one. Iron has a natural tendency to go into solution. It is a well-known fact that if a piece of bright iron be immersed in a solution of copper sulphate, the metallic copper will be plated out on the iron, and the iron will replace the copper in the solution as shown by the following equation:

$$Fe + CuSO_4 = Cu + FeSO_4.$$

The explanation of this phenomenon, according to the modern theory of solutions, is that copper sulphate is an electrolyte* and in a solution is partially dissociated into its ions, Cu and SO_4. There are present in the solution the positively charged copper ions which have less solution pressure than the positively charged iron ions; hence the former are attracted to the negatively charged metallic iron; the electric charges are neutralized, and metallic copper is precipitated. This action continues because the copper is a conductor and does not re-dissolve in the presence of iron for the reason explained above.

Water, like copper sulphate, is dissociated to a small degree into hydrogen, H+, and hydroxyl, OH—. Its formula may be written as

$$H^+ - OH^-.$$

From an electro-physical standpoint, hydrogen is a metal and acts like copper; that is, it plates out on the metallic iron at the negative pole, while the iron takes its place in solution. However, the hydrogen is not liberated readily upon the surface of the iron, and soon the condensation of gaseous hydrogen, which is a non-conductor, on the surface of the iron checks the action. In order that the solution of iron may proceed further, the force which prevents the hydrogen from being liberated as a gas on the surface of the iron must be overcome. This is accomplished by what the physical chemists term over-voltage; that is, it is necessary to increase the concentration of the hydrogen ions in the solution in order to force the liberation of hydrogen gas, or, as one may say, that the bubbles of gas may be crowded off the surface of

*An electrolyte is a solution which conducts current. The modern theory of solutions considers that electrolytes, when dissolved in water, are separated or dissociated into component parts called ions. Thus common salt is dissociated into its Na ions, which are positive, and its Cl ions, which are negative; Gypsum, $CaSO_4$, into Ca ions which are positive and SO_4 ions which are negative. Any compounds thus dissociated, that is, separated into their ions, conduct current.

the iron. Then the iron goes into solution as ferrous hydrate, hydrogen being evolved. The equation is as follows:

$$Fe + 2H\,OH = Fe\,(OH)_2 + 2H.$$

Acids like carbonic acid ($H_2\,CO_3$), or sulphuric acid ($H_2\,SO_4$), added to water greatly increase the concentration of the hydrogen ions and promote solution; while alkalies like lime $Ca\,(OH)_2$, or caustic soda $Na\,OH$, increase the concentration of the hydroxyl ions and check solution.

Dr. Allerton S. Cushman,* Professor W. H. Walker, and others† have shown that a piece of ordinary iron, which is never homogeneous, immersed in water acts like an electrolytic couple, that is, it produces electric currents, the particles of metallic iron acting as positive poles, and the particles of carbon, graphite or scale, as negative poles. They have shown that the hydrogen is deposited and later given off at the negative poles, while the solution of iron in the form of ferrous hydrate takes place at the other. In an acid water, the one which corrodes iron most readily is that which has the largest excess of hydrogen ions.

The conclusion from all these studies is that, in the absence of oxygen, iron exists in water as the ferrous or unoxidized hydrate. This is quite soluble in water; in the amounts usually found in water, entirely soluble.

The iron in water may be from vegetable or mineral sources. The mineral sources are the iron silicates, carbonates, sulphates, chlorides, phosphates, oxides, etc. The chief vegetable source is the iron in plants, living and dead, beginning with the green chlorophyl of the leaves of plants, a compound of iron, and extending through leaf mould, peat, and lignite, to anthracite. Generally speaking, all these compounds are derivatives of oxides.

These deposits of iron are more or less soluble in water which is free from oxygen, and especially so in water containing acid. The degree of solution is proportional to the amount of the acid, because it is the excess of hydrogen ions which effects solution. Carbonic acid is most important in this connection, not because it is a strong acid, which it is not, but because its amount is usually far greater than that of any other acid present in water.

The primary source of carbonic acid is the organic matter in the

*Bulletin No. 30, Office of Public Roads, U. S. Dept. of Agriculture.

†"The Corrosion of Iron and Steel," *Journal*, Am. Chem. Soc., 29, 125.

soil. The rain water which falls on the earth is saturated with oxygen, and, before its passage through the ground, it will not dissolve iron from mineral although it may from vegetable sources. The upper soil layers are rich in organic matter; the organic matter undergoes oxidation, oxygen is absorbed and carbon dioxide is evolved—the water loses its oxygen and becomes charged with carbonic acid. More extended decomposition of organic matter in the absence of oxygen may produce hydrogen sulphide and methane. One or both of these gases may be dissolved in ground-water, according to its previous history, and increase its solvent power. The occurrence of a black, peaty layer overlying white sand containing iron, the white sand in turn overlying red sand containing oxidized iron, is a familiar sight to all engineers who have made excavations. Here the carbon dioxide produced by the decomposition of the organic matter has caused the solution of the iron from the upper layer, has carried it down through the white sand, and has kept it in solution until the iron has become oxidized and re-precipitated in the layer beneath. Wells sunk beneath such soil may be free from iron at first, but continued pumping may cause so much water to pass through the soil that it is robbed of its small amount of oxygen when the iron goes into solution and appears in the well water. This case is met frequently in practice.

It is stated by many geologists that carbon dioxide is frequently of volcanic origin, resulting from the decomposition of iron carbide by iron oxide at high temperatures. This may explain the presence of iron in the waters of deep wells far removed from any deposits of organic matter. The organic acids, for example, crenic and apocrenic acids, may also aid the solution of iron. The waters of certain Brazilian rivers which contain large amounts of organic acids are said to be very corrosive, and the bottoms of iron boats are attacked rapidly. The production of hydrogen sulphide in the presence of iron and organic matter results in the formation of ferrous sulphide. This is insoluble, but if exposed to the air it readily oxidizes to ferrous sulphate which is very soluble in water. This is usually the explanation of the presence of ferrous sulphate in the so-called "acid iron" waters.

As stated later, manganese sulphide behaves in a similar manner, with the formation of manganese sulphate and, in the absence of alkalies, of free sulphuric acid, which in turn effects a rapid solution of the iron and manganese with which the water comes in contact.

Iron (or manganese) in water may be: (1) In the unoxidized or ferrous condition, when it is soluble in water; (2) In the oxidized or ferric condition, when it is almost insoluble in water containing oxygen; (3) In the colloidal or semi-soluble form, when it may be oxidized, yet to all outward appearances in solution. Perhaps there is, in addition, an insoluble, vegetable compound of iron which is present in the colloidal form.

According to Schwers* such a vegetable compound of iron is produced by the oxidation of organic matter to organic acid by ferric hydrate. The organic acid thus formed combines with the iron to form an insoluble organic salt of iron which is exceedingly difficult to treat. This compound is formed after the water is drawn from the ground and after a portion of the iron has oxidized.

Ferruginous ground-waters are of three general classes: (1) Those which begin to precipitate the iron immediately after aeration, like many of the waters of North Germany; (2) Those which will hold the iron in solution indefinitely, even after aeration, like the dark brown water of deep wells or the acid waters from mines; (3) Those which precipitate a part of the iron within a few hours and hold the remainder in solution indefinitely, like the water at Reading, Mass.

Clear and colorless ferruginous ground-waters never contain oxygen. When both oxygen and iron are present, the water is either turbid or colored. In the latter case the iron is held in solution or suspension by vegetable matter.

The amount of iron in water varies from a slight trace to more than 2 500 parts per million. Manganese does not usually occur in large amounts, although on one occasion more than 220 parts per million were found in the Breslau supply. As a rule, however, the waters used for water supplies contain less than 10 parts of iron per million and only small amounts of manganese. The average iron content of certain ground-waters is given in Table 2, which also indicates roughly the geographical distribution of ferruginous water. It will be deduced that the ground-waters of Bavaria, Baden, Austria, Switzerland, Scandinavia, Italy, and parts of North America, seldom contain iron, and it is believed that the same is true of large parts of Russia, Siberia, Asia Minor, France, and the Spanish Peninsula, although analytical

*Révue d'Hygiène, 30, 192.

data are wanting in this connection. The writer has not been able to obtain very much information concerning the iron content of the waters of the British Isles. It is a well-known fact, however, that some of the hard well-waters of England contain more or less iron, and that it can be removed by the softening process.

Generally the waters which contain manganese contain still more iron. In one case, however, at Halle, the amount of manganese exceeds that of iron.

TABLE 2.—Amounts of Iron in Various Ground-Waters.

(Parts of Fe per Million.)

Locality.	Fe.	Locality.	Fe.
Aguas de Bar, Spain	61.	Indianapolis, Indiana	41.
Arad, Hungary	25.	Joplin, Mo.	0.3
Asbury Park, N. J.	9.1	Kiel, Germany	4 to 7
Aurich (Friesland)	19.2	La Grange, Mo.	1 5
Berlin, Müggelsee	1.3	La Reid, Belgium	0.97
Berlin, Tegel	1.0	Leipsic, Germany	3 to 14
Blanchimont, Belgium	21.3	Lowell, Mass.	3.1
Bloomfield, Conn.	15.	Manchester, Mass.	0.07
Brunswick, Germany	6.0	Manheim, Germany	0.13
Brée, Belgium	6.8	Marblehead, Mass.	3.87
Breslau, Germany	6 to 400.	München-Gladbach, Germany	2.3
Centreville, Iowa	3.2	Posen, Prussian Poland	7.1
Charlottenburg, Germany	1.4	Provincetown, Mass.	3.6
Chaudfontaine, Belgium	6.3	Reading, Mass.	1.21
Chevron, Belgium	40.6	Richmond, Mo.	12.0+
Cohasset, Mass.	1.3	Seraing, Belgium	0.25
Court St. Etienne, Belgium	6.3	Spa (Poulion Pierre le Grand), Belgium	36.2
Diepenbeck, Belgium	4.	Stargard, Germany	2.0
Far Rockaway, N. Y.	2.48	Superior, Wis.	1.7
Garrettsville, Ohio*	2.0	Tampa, Fla. (Sulphur spring water)	1.0
Glogau (Germany)	5.8	Tougres (Montagne de fer)	62.2
Gottelheim (Westphalia)	110.	Turnhout	12 to 20
Halle, Germany	0.8	Webb City, Mo.	213.1
Hamburg, Germany	2.0	Winona, Minn.	0.6
Hanover, Germany	0.5		
Huy, Belgium	8.		

Professor Edward Bartow, Director of the Illinois State Water Survey,† gives the variation in the amounts of iron in the waters of Illinois as follows:

In springs, from traces to 997 parts of iron per million;

In drift wells, from traces in several wells to 11 parts per million in a well at Paris, Edgar County, the higher quantities being found in the deeper wells;

In rock wells, from traces in many wells to 2 506 parts per million in a deep well at Kell, Marion County.

The majority of these wells have less than 3 parts of iron per million.

*Furnished by Mr. Winthrop Pratt.

†Illinois State Water Survey, Bulletin No. 4.

TABLE 3.—Amounts of Manganese in Various Ground-Waters.

(Parts of Mn per Million.)

Locality.	Mn.	Locality.	Mn.
Arad, Hungary	Present	Halle, Germany	1.50
Babylon, N. Y.*	0.07	Hamburg, Hofbrünnen	0.45
Bayshore, N. Y.*	0.37	Hanover, Germany	Present
Berlin, Germany	Present	Patchogue, N. Y.*	0.20
Björnstorp, Sweden	3.4 to 53.4	Reading, Mass.	0.004 to 0.56
Brunswick, Germany	Present	Stargard, Germany	Present
Breslau, Germany	Trace to 110	Stettin, Germany	5.22
Calverton, N. Y.*	0.30	Superior, Wis.†	0.12

The amount of iron which will cause trouble varies with the water. Allen Hazen, M. Am. Soc. C. E.,‡ states that a water containing 0.3 part of iron per million rarely precipitates, and that 0.5 part is the allowable limit. This is a good general rule. However, certain waters in the Rhine provinces, which contain as little as 0.1 part of iron per million, deposit iron oxide in the distribution system, while some American deep well-waters which contain nearly 1.0 part of iron per million are used without complaint.

The Deterioration of Ground-Water Supplies.

Many ground-water supplies, which when first put into service furnish excellent water, are found in later years to contain gradually increasing and objectionable amounts of iron. The Massachusetts State Board of Health has made a study of the 78 ground-water supplies in the State in use at the end of 1905.§ One of these supplies, Bradford, was so bad that it was abandoned; the supply at Reading has to be purified; that at Marblehead is to be purified, and many of the others now contain objectionable amounts of iron which should be removed. Table 4, abstracted from the report, shows how the amounts of iron have increased in ten years. No results of tests for manganese have been published.

Fig. 3 shows the increase in the amount of iron in the Reading water supply.

*Data furnished by A. D. Flinn, M. Am. Soc. C. E.
†Sample furnished by Mr. W. C. Lounsbury.
‡"Filtration of Public Water Supplies," p. 186.
§Report for 1905.

TABLE 4.—The Amounts of Iron in Certain Massachusetts Ground-Waters.

City or Town.	To 1895.	1896–1900.	1901–1905.
Amesbury	....	0.40	0.67
Billerica	....	0.18	0.36
Brookline	0.02	0.03	0.15
Fairhaven	0.01	0.12	0.15
Framingham	0.14	0.10	0.14
Hyde Park, wells near Neponset River	0.14	0.16	0.41
Lowell, Boulevard wells	....	0.32	0.32
Marblehead	0.38	1.19	2.03
Methuen	0.13	0.09	0.28
Middleboro	0.19	0.35	0.96
Newton	0.12	0.06	0.13
Waltham	0.04	0.15	0.31
Wellesley	....	0.05	0.08
Winchendon	....	0.09	0.28
Woburn	0.01	0.02	0.05

The Board reports that:

"The deterioration is usually most marked in those sources which are located near a pond or stream, the water being derived in such cases in part from the rain which falls upon and sinks into the ground in the neighborhood of the collecting works, and in part by percolation through the ground from the neighboring surface source * * *."

"Iron is frequently present in water which has passed through peat and other soil containing a large quantity of organic matter, and which has not been subsequently purified in its passage through sand or gravel to the collecting works; and in some cases the deterioration of ground-waters has been due to the reduction in efficiency of the filtration of water which has taken up organic matter and iron from peat or muck near the surface of the ground. An example of such deterioration is found in Billerica, where the wells are located in the midst of an extensive meadow which contains at the surface a deep deposit of organic matter."

The Board also demonstrates that increased draft is often responsible for the deterioration in the character of the water. "At Lowell a great improvement was made in the quality of the water drawn from the ground in the vicinity of the Merrimack River by an extension of the collecting works." A like improvement has been observed in other places, but it is usually of a temporary character only.

There has been an unfortunate tendency in cases where the iron has increased, as in the above, to abandon the ground-water supply, with its invested capital, and seek another source. Such a ground-water, purified, would be safer than a filtered surface-water, and in most cases more economical.

Reading, Mass., Water Supply.

There is no iron-containing water in the writer's experience which has been so instructive as that from the Reading, Mass., filter gallery. Fig. 2 shows the location and construction of this gallery.

The Reading filter gallery was built in 1890 by the late M. M. Tidd, M. Am. Soc. C. E. It consists of a permeable masonry tunnel 2.5 ft. wide, 4.0 ft. high, and 240 ft. long, placed in the water-bearing gravel beneath the littoral marshes of the Ipswich River which frequently overflow its banks. The bottom of the gallery is 22 ft. below the surface of the ground, while the normal ground-water level, even during droughts, is rarely 10 ft. below the surface. Water is pumped

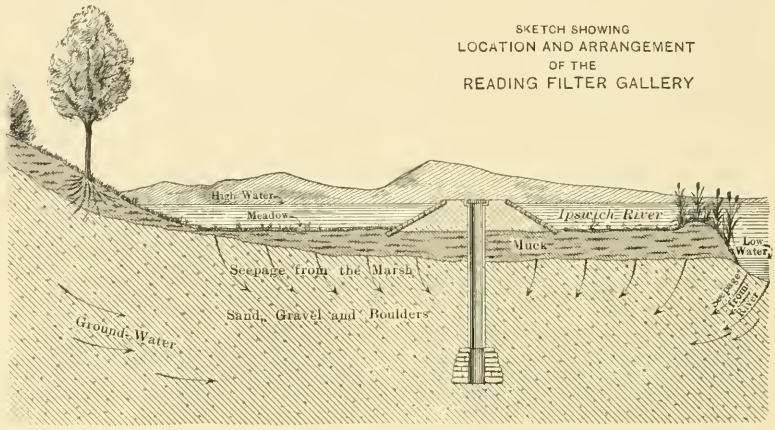

Fig. 2.

from the gallery for about 6 hours per day, on an average, and, at certain times of the year, the ground-water level may be depressed more than 20 ft. below the surface just before pumping is finished. The water in this gallery is a mixture of three kinds, namely,

1. The true ground-water which is flowing from the higher land toward the river;

2. The seepage from the peaty matter immediately above the gallery; and

3. The water which filters directly into the gallery from the river.

All these components are different in character, and, consequently, the mixture not only varies with the season, but, at times, with the hours in a single day. According to Desmond FitzGerald, Past-Presi-

dent, Am. Soc. C. E., more than half the water collected in 1893 came from the Ipswich River. If the water from the ground itself could be kept separate, it probably could be purified by simple aeration and filtration. The river water is somewhat colored with vegetable matter, contains oxygen, and could be coagulated with sulphate of alumina without difficulty. The seepage from the overlying peaty layer is rich in humus-like bodies, and is the cause of most of the difficulties which have been experienced. When, after a prolonged drought, there comes a heavy rain or a sudden overflowing of the meadow, the humus substances are dissolved to a considerable degree, and, seeping downward, become mixed with the gallery water. These substances form compounds with iron which without special treatment will not coagulate and precipitate for weeks, although the iron is oxidized quite readily. When the water containing humus matter and iron is heated, the color deepens. Boiling, which usually hastens the precipitation of iron from a ground-water, only serves to form more of this compound of iron with organic matter and to keep the iron longer in suspension. Carbon dioxide, however, prevents the formation of this compound, and water fresh from the wells and treated with carbon dioxide before the compound is formed can be freed from iron more readily than is the untreated water. On the other hand, the addition of carbon dioxide after the compound has once formed seems to have little or no effect upon the precipitation of the iron.

These facts are shown by the following experiments:

Experiment No. 1.—Effect of Boiling.—A sample of water was collected on February 17th from the Reading filter gallery and boiled 5 min. During boiling the color increased from 70 to 120. The amount of iron in the sample was 3.4 parts per million, 3.3 parts of which were in the oxidized condition. The boiled sample was cooled, aerated, and allowed to stand for 24 hours. It was then filtered through paper and found to contain 2.9 parts of iron per million. The filtered untreated sample contained 1.6 parts of iron per million.

Experiment No. 2.—Effect of Addition of Carbon Dioxide to Fresh Sample.—To two samples of fresh Reading water containing 3.4 parts of iron per million were added: (*a*) 50 cu. cm. of distilled water charged with carbon dioxide; (*b*) 50 cu. cm. of plain distilled water. The latter sample was the control.

After two weeks in tightly sealed bottles, the following amounts

of iron were found in the filtered samples: (*a*) 0.3 part per million; (*b*) 3.3 parts per million. After a month, the filtered untreated water still contained iron.

Experiment No. 3.—Effect of Addition of Carbon Dioxide to Sample of Stale Water.—A sample of water, not freshly drawn, containing 2.5 parts of iron per million, was treated with carbon dioxide as in Experiment No. 2. After three days the treated sample filtered through paper contained 1.4 part, and the untreated or control sample, 1.1 part of iron per million. After one week the amount of iron in the treated sample had dropped to 1.0 part, and in the control to 0.92 part per million.

Analytical Characteristics of Typical Reading Waters.

Table 5 gives the results of three analyses of samples collected on February 17th, April 2d, and July 4th, 1908, respectively.

The first sample represents water which contains the iron and organic matter compound which is so difficult to treat. The second sample, on the contrary, is one from which the iron is removed with less difficulty. The third sample contains the minimum of seepage water. The most important hindrance seems to be the organic matter, as shown by the color and albuminoid ammonia, while the presence of nitrite is an indication of seepage from the overlying peaty deposits.

TABLE 5.—Results of Analyses of Reading Water.

(Parts per Million.)

Source of sample	Reading, Mass., Filter Gallery.		
Date of collection	Feb. 17, 1908	Apr. 3, 1908	July 4, 1908
Date of examination	Feb. 18, 1908	Apr. 4, 1908	July 6, 1908
Temperature, in degrees centigrade	6.5	.....	12.
Odor: Cold: 20° cent.	1-Vegetable	0-	0-
Odor: Hot: 90° cent.	2- "	1-Vegetable.	1-Vegetable.
Turbidity: Silica standard	.....	2	.....
Color: Platinum standard	70	40	53
Color of boiled water	120	74	85
Increase in color	50	34	32
Oxygen consumed	6.9	4.5	.....
Nitrogen as: Free ammonia	0.130	0.068	0.054
Nitrogen as: Albuminoid ammonia	0.178	0.092	0.102
Nitrogen as: Nitrites	0.006	0.002	0.000
Nitrogen as: Nitrates	0.15	0.20	0.10
Chlorine	10.	7.5	.....
Hardness, by soap method	50.	.....	23.
Alkalinity	10.	9.	12.
Residue on evaporation	130.	79.	102.
Iron	3.3	1.8	1.91
Iron in filtered sample	3.3	1.6	0.90
Carbon dioxide (free)	.....	28.	36.
Dissolved oxygen	1.4	.....	1.55
Manganese	0.33	0.004	0.000

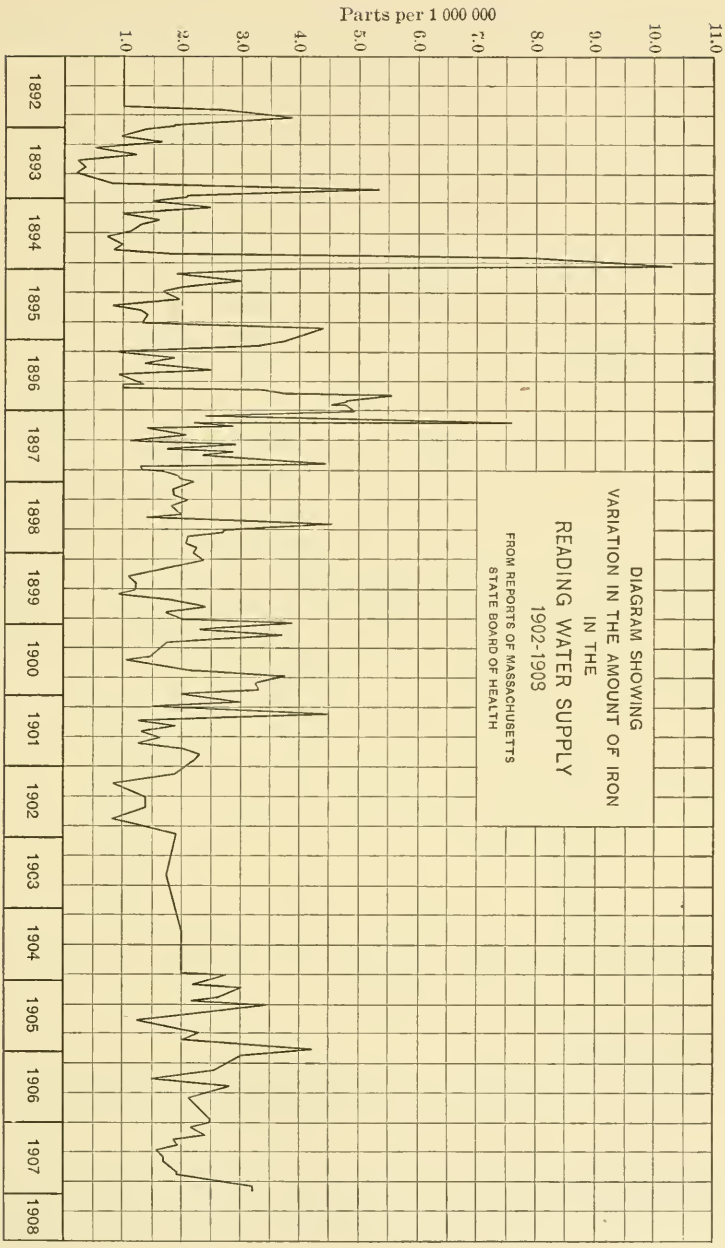
Parts per 1 000 000
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
DIAGRAM SHOWING
VARIATION IN THE AMOUNT OF IRON
IN THE
READING WATER SUPPLY
1892-1909
FROM REPORTS OF MASSACHUSETTS
STATE BOARD OF HEALTH
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908

Fig. 3.

In a single day some of the constitutents may vary as shown by tests made on July 4th, 1908, the results of which are given in Table 6.

TABLE 6.

Time.	Parts per Million.		
	Iron.	Carbon dioxide.	Dissolved oxygen.
7.15 A. M.	4.30	35	2.15
8.45 "	2.28	41	0.80
9.00 "	....	38	....
9.30 "	2.20	37	0.46
10.00 "	....	35	2.15
11.00 "	1.45	36	0.80
12.00 M.	1.70	39	0.86
1.00 P. M.	....	..	2.39
1.15 "	1.70	..	2.42
1.30 "	....	..	1.23
2.00 "	2.20	37	2.98
3.00 "	....	34	1.41
3.40 "	1.90	..	1.89

Iron accompanied by color and organic matter coagulates very slowly. An average sample of water collected on February 20th, 1908, was allowed to stand in a bottle exposed to the air. At the beginning of the experiment it contained 1.5 part of dissolved iron per million. After various periods of time it contained the following amounts:

Elapsed time.	Dissolved iron, in parts per million.
Beginning	1.5
1 month	0.8
1.5 months	0.7
2.0 "	0.65
2.5 "	0.6

The quantity of iron in a ground-water may vary greatly, as shown on Fig. 3. This diagram gives the amount of iron in the Reading water since 1892, as determined by the Massachusetts State Board of Health.

Naturally, the methods for purifying such a water as that from Reading must be varied because the water varies in character. The iron exists in many physical states, and its removal is at times beset with many hindrances. Sometimes the chemical reactions (simple oxidation) are not interfered with; at other times the iron may be oxidized, but in such a physical state that it will not be precipitated

within a reasonable time. It may be said to be in the colloidal condition—or in semi-solution.

Properties of Colloidal Mixtures.

The theory of the iron-removal process has a physical as well as a chemical basis, and it is necessary at this point to define briefly the nature of solutions in general in order that the nature of the dilute solutions of iron in natural water in particular may be better understood. Any brief résumé must be inadequate, but more detailed information may be found in recent chemical literature.*

For the purposes of discussion, all solutions or suspensions in water are called mixtures, and of these mixtures physical chemists recognize three groups:

A.—Solutions of crystalloids (*e. g.,* salt in water).

B.—Colloidal solutions (*e. g.,* gelatine in water).

C.—Colloidal suspensions (*e. g.,* extremely finely divided clay in water).

Nearly fifty years ago the English scientist, Thomas Graham,† separated all substances which form solutions, that is, homogeneous mixtures with water, into two groups, namely, crystalloids and colloids. Common salt is a crystalloid. It dissolves in water and can be crystallized from water unchanged. It exerts osmotic pressure, that is, it will diffuse through parchment. The solution is not viscous. Gelatine is a colloid. It dissolves in water to form a viscous solution, and will solidify or gelatinize when the solution is cooled. It will not dialize‡ through parchment, and, therefore, the osmotic pressure is very low.

The names arose because the crystalloids usually separated from their mixtures as crystals, while the colloids separated in an amorphous or glue-like state, hence "colloid" from the Greek word, *"kolla,"* meaning glue.

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*A. Lottermoser, "Anorganische Kolloide"; A. Müller, "Die Theorie der Kolloide"; "Allgemeine Chemie der Kolloide"; G. Bredig, "Anorganische Fermente"; A. A. Noyes, "The Preparation and Properties of Colloidal Mixtures"; *Journal*, Am. Chem. Soc., 27, 850; Zsigmondy, "Zur Kenntniss der Kolloide."

†*Annales de Chimie et de Physique*, 1-77, 121 (1862); 3, 127 (1864).

‡Dialize, from the Greek *"dia"* (through) and *"luein"* (to loose), meaning to separate by taking advantage of the unequal diffusion of certain substances especially through permeable membranes; for example, if a parchment bag filled with salt solution be suspended in running water, it will be observed that the salt diffuses through the parchment bag after a short time, while a solution of gelatine similarly treated would remain within the bag indefinitely. This method is used to separate colloids from crystalloids.

Crystalloids diffuse through colloids, but colloids are impenetrable to other colloids; for example, if a stick of agar (a jelly made from a Japanese seaweed) be immersed in a solution of salt, it will be found that the salt will diffuse through the agar with almost the same rapidity as through water, while, if the agar be immersed in melted gelatine, no penetration will occur.

Both crystalloids and colloids in solution pass through filter paper unchanged, but the latter do not penetrate parchment. Of these colloidal mixtures there are two classes. Glue is typical of one class. When its mixture with water is evaporated, it gelatinizes and can be recovered and re-dissolved repeatedly. The addition of a moderate amount of a substance like salt does not cause it to coagulate and precipitate. The mixture is more viscous than water, and the viscosity increases with the amount of glue dissolved.

The second class of colloidal mixtures is entirely different. It is possible to divide metallic gold into such fine particles that it will remain suspended in pure water indefinitely, and, furthermore, will offer no more resistance to the passage of light than that afforded by solutions of certain crystalloids. This mixture, ruby red in color, will pass through filter paper unchanged, but, unlike glue, cannot be re-dissolved in water after being precipitated, without long-continued shaking and agitation of the particles. By means of the ultramicroscope and special methods of lighting, particles of gold as small as 0.000002 mm. have been measured, and it is stated by some that the particles in this mixture approach the gold molecule in size. The mixture is permanent if the water be pure, but if a small quantity of any salt (any electrolyte) be added to the mixture, the gold is immediately precipitated and cannot be resuspended except by prolonged shaking with pure water. This mixture is not viscous as are those of the first class. Many other substances act like metallic gold, for example, filter paper, kaolin, metallic sulphides, and even glass. Professor A. A. Noyes calls the first class (viscous, gelatinizing colloidal mixtures not coagulated by salts) colloidal solutions, and the second class (non-viscous, non-gelatinizing, but readily coagulable mixtures) colloidal suspensions.

The dividing lines between these groups have not as yet been clearly defined. In fact, there is some doubt if they can be defined. To illustrate, it has been shown by experiment that after a homogeneous

solution of ordinary soda and water is whirled rapidly in a centrifugal machine for a considerable time, the concentration of the soda in the solution is greatest in the circumference and least at the center. This leads one to ask if the differences between these various bodies are not simply differences in the sizes of the particles, differences in degree rather than in kind. Is not this true of colloids at least, which, although they pass through a coarse filter like paper, cannot pass through a finer filter like parchment, perhaps because of the well-known greater sizes of their molecules? Are not colloidal suspensions simply mixtures where the substances in suspension have been subdivided into particles so fine that the effect of gravity is overweighed? No satisfactory answer to this question has yet been given, but without going deeper into the chemical theory, the writer would state that electrical forces have something to do with keeping some of the bodies in solution or suspension, that is, the particles are kept in constant motion by electric force, and cannot subside.

Colloids suspended in water may be separated into two groups: First, those which when subjected to the influence of an electric current migrate toward the negative pole, that is, move with the current. These are called positive colloids. Second, those which migrate toward the positive pole, that is, against the current. These are called negative colloids.

The problems connected with the purification of ground-waters containing iron and manganese are those of the coagulation and precipitation of the positive suspended colloids, such as the hydrates of the metals (iron hydrate, manganese hydrate, etc.). The coloring matters in some of the highly colored deep-well waters, like the deep-well waters of the Mississippi Delta and those proposed for the water supply of Posen (Prussian Poland), and, perhaps, the Dismal Swamp, are largely negative colloids. The finely divided suspended clay in muddy river water is also a negative colloid.

Fig. 4 illustrates the classification of colloids.

Theory of the Deferrization Process.

Iron (or manganese) in the water of springs and wells is in the form of a colloidal mixture. If the water remained pure, this mixture would be permanent. Soon after aeration, however, the salts dissolved in the water, the presence of suspended matter, or contact with filter-

ing material, one or all, cause the colloid to coagulate and to precipitate as amorphous matter; in the case of iron, as amorphous ferric hydrate which when dried becomes ordinary iron rust—ferric oxide. The chief difficulty in the deferrization process is to precipitate the colloidal iron hydrate within a reasonable length of time, and all schemes and devices try to accomplish this end.

PROPERTIES OF SOLUTIONS:

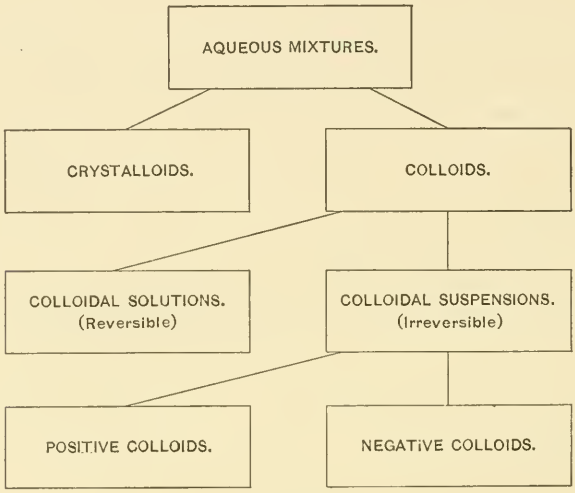

FIG. 4.

Herr A. Schmidt and Herr K. Bunte, of the Technological High School at Karlsruhe,* and others, have made studies of the chemical reactions which take place during the deferrization process. The process may be divided into phases as follows:

1.—The first requirement for the precipitation of iron is the presence of oxygen by which the oxidation of the iron is effected.

2.—The oxidation of ferrous hydrate depends on hydrolysis or the decomposition of water, as expressed in the following equation:

Ferrous Hydrate. Water. Oxygen. Ferric Hydrate. Water.

$$2Fe\begin{matrix}OH\\OH\end{matrix} + 2H\text{–}OH + O = Fe\begin{matrix}OH\\OH\\OH\end{matrix} + H\text{–}OH$$

3.—The ferrous hydrate becomes oxidized into the insoluble ferric

Schillings Journal für Gasbeleuchtung und Wasserversorgung, loc. cit.

hydrate which exists in the form of a colloidal suspension and remains in solution until finally—

4.—The transformation of the colloidal suspension into the insoluble, gelatinous ferric hydrate is effected by various conditions which exert a helpful influence on this action, at last causing the iron to precipitate as amorphous ferric hydrate.

The discussion of the subject may be separated into divisions corresponding to the different steps in the process, namely: The absorption of oxygen; the oxidation of the iron; and the precipitation of the oxidized iron.

The Absorption of Oxygen.—When it is realized that 1 part of oxygen will oxidize 7 parts of iron, $2\ FeO + O = Fe_2O_3$, that is, 1 cu. cm. of oxygen will oxidize 10 mg. of iron, and that water under ordinary barometric pressure (760 mm.) and ordinary temperature (20° cent. or 68° Fahr.) will absorb a maximum of 9.19 parts of oxygen per million, or 6.32 cu. cm. per liter, it will be realized how easy it is to supply the necessary oxygen to a water to be purified. Often a leaky suction, badly packed glands, or a small air-cock will admit a sufficient quantity. Often the filtering layer in pressure filters filled with shavings, bone charcoal or magnetite will store up enough oxygen during washing or when standing idle to oxidize the iron in the water filtered between times. If this were not so it would be as impossible to explain the success of closed filters under certain conditions as it is easy to explain why these filters fail when there is more iron present than oxygen to oxidize it.

Neither oxides of tin nor the iron ores which have been used as filtering material give up their combined oxygen to water, but Schmidt and Bunte* found that 575 g. of brown hematite contained 70 cu. cm. of various gases which had condensed on the surface of the material, while Dunbar and Kryck* have shown how oxygen is absorbed from water and air by the moist ferric hydrate which collects on the surface of the gravel and sand in aerator or filter while the devices are standing empty.

This explains why aeration is not always necessary with intermittent filters, and why Piefke* found that his coke aerator required three months to reach its maximum efficiency, that is, three months to collect a good coating of moist iron hydrate.

Loc. cit.

Water standing in tanks and reservoirs absorbs oxygen very slowly. In 6 hours, under ordinary conditions, it rarely penetrates to a depth of more than 4 in. The air and water must be brought into more intimate contact by shaking, spraying, or by cascades; by letting the water fall through towers filled with either coke, brick, broken stones, wooden slats, or by any other arrangement which will expose the water in thin layers to the air.

Oesten* has observed the increases shown in Table 7, in dissolved oxygen, when a water was sprayed from varying heights.

TABLE 7.

Height of Fall.		Oxygen absorbed, in parts per million.
Centimeters.	Inches.	
10	4	1.21
25	10	1.79
50	20	2.52
100	40	6.50
200	80	7.33

In an aerator tower, 3 ft. high, filled with 1-in. broken stone, at Reading, Mass., the writer observed the following degree of absorption of oxygen, the period of aeration being about 5 sec.

	Dissolved oxygen, in parts per million.
Well water	2.0
Aerated water	3.20
Absorbed in 5 sec.	1.20

Thus it will be seen that it is a very easy matter to supply water with the necessary oxygen.

Dunbar and Kryck have shown that iron can be oxidized when the minimum amount of oxygen necessary to combine with the iron is present; and, furthermore, have proved that the desirability of removing the carbon dioxide has been over-emphasized. To be sure, other things being equal, the presence of carbon dioxide retards the oxidation of iron, and, furthermore, Dunbar and Kryck worked with a water which contained many of those salts which assist precipitation and, therefore, might minimize the effect of the carbon dioxide.

*Schillings Journal für Gasbeleuchtung und Wasserversorgung, 34, 283.

On one occasion, however, they added 297 parts of carbon dioxide per million to an aerated water which already contained 150 parts of carbon dioxide, and succeeded in reducing the iron to 0.2 part per million by subsequent filtration, which result was neither better nor worse than those obtained without this excessive amount of carbon dioxide. The filtered water contained 447 parts of carbon dioxide per million.

Not only is excessive aeration unnecessary in most cases, but in some it is exceedingly undesirable, because it renders the precipitation of the iron more difficult. It has already been shown that compounds of iron and humus matter are difficult to treat, that they result usually from a mixture of the seepage from peaty deposits with iron-containing ground-water, and that the presence of carbon dioxide which would be removed by excessive aeration prevents the formation of this compound and allows the iron to be oxidized and removed.

One advantage in removing carbon dioxide by aeration is the diminution of subsequent corrosive action in the distribution system.

Oesten* observed at the Zoological Garden, in Berlin, that iron was dissolved from the service pipes by the aid of the carbonic acid left in the water after single filtration, as shown by Table 8, which gives analyses of samples from different parts of the Garden.

TABLE 8.

Source of sample.	Dec. 10th, 1907. Pumps working. FeO.	Dec. 17th, 1907. Pumps idle. FeO.
1. Raw water	2.04	3.77
2. Filtered water	0.26	0.30
3. Old bird house	0.88	0.51
4. Old ape house	0.13	0.17
5. Deer yard	0.26	3.66
6. Pheasant house	0.35	0.30
7. Hippopotamus house	1.41	5.15
8. Elephant house	....	1.07

These results were confirmed by another set of analyses of samples taken on January 11th, 1908, when the filtered water was found to contain 0.21 part, the double filtered water less than 0.01 part, and the water from the old ape house, 0.13 part of ferrous oxide per million.

The solvent effect of the water has been greatly reduced by double filtration with the consequent aeration.

Schillings Journal für Gasbeleuchtung und Wasserversorgung, 51, 203.

Oxidation of the Iron.—The oxidation of iron is effected by hydrolysis, that is, the molecule of water, H OH, is split into H and OH, its ions; the OH ion combines with the ferrous hydrate to form the ferric hydrate, while the hydrogen unites with the free oxygen to form water. This action (hydrolysis) is retarded by acids and accelerated by alkalies and by contact with rough surfaces such as the material used in filters and aerators, or the ferric hydrate which has already been precipitated. It is what is known as a "time reaction," and may be expressed mathematically by Prinz's* formula, as follows:

A = original amount of ferrous (unoxidized) iron,

t = time since oxygen was admitted—elapsed time,

x = iron oxidized during elapsed time.

$$K = \frac{1}{t} \times \frac{A}{A - x} = \text{Coefficient.}$$

K is a coefficient which varies directly with speed of reaction, and waters showing high values of K are most readily purified. Many workers, including Proskauer,† Piefke,‡ Fischer,§ Luebbert,|| Dunbar,¶ Darapsky,** Schmidt and Bunte,†† and Clark,‡‡ have discussed this reaction from many points of view, and the subject will be dismissed with two illustrations:

1.—The influence of an acid, for example, carbonic acid.

The experiment by Schmidt and Bunte, in Table 9, with two waters containing 9.5 parts of iron per million and differing in their carbon dioxide content only, shows how the presence of carbon dioxide retards the oxidation of iron.

The value of K in the water rich in carbon dioxide averages 1.8; in the other water, 15. This means that a fourfold increase in the amount of carbon dioxide has decreased the speed of oxidation eightfold. G. Just§§ has stated that in solutions of ferrous carbonate the velocity of reaction is inversely proportional to the square of the concentration of the carbonic acid.

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*Schillings *Journal für Gasbeleuchtung und Wasserversorgung*, 35, 164.

†Proskauer, *Zeitschrift für Hygiene* (1890), 9, 148.

‡Piefke, *loc. cit.*

§Fischer, *Zeitschrift für Hygiene* (1893), 13, 251.

||Luebbert, *Zeitschrift für Hygiene* (1895), 20, 397.

¶Dunbar, *Zeitschrift für Hygiene* (1896), 22, 68.

**Darapsky, *Gesundheits-Ingenieur*, 1904.

††Schmidt and Bunte, *loc. cit.*

‡‡Clark, Report, Mass. State Board of Health, 1891; also, *Journal*, New England Water Works Assoc., 11, 277.

§§Berichte der deutschen chemischen Gesellschaft, 40, 3 695 (1907).

TABLE 9.—The Influence of Carbon Dioxide on the Speed of Precipitation of Iron from Water.

Elapsed time since the beginning of reaction, in hours.	Iron found in the solution, in parts per million.	Free CO_2, in parts per million.	Oxygen, in cubic centimeters per liter.	K
A WATER RICH IN CARBON DIOXIDE.				
0	0.5	270	4.07	1.3
4.25	9.0	....	5.35	1.6
8.25	8.3	192	4.50	1.5
24	6.7	150	4.55	2.3
33	4.45	145	4.86	2.2
48	3.3	140	4.90	2.1
96	1.26	126	5.16	2.0
120	0.82	117	5.20	1.7
168	0.51	92	5.35	...
WATER LOW IN CARBON DIOXIDE.				
0	9.5	60	4.68	25
3	4.5	58	5.08	16
7	3.37	55	5.08	13
24	0.41	38	5.2	12
31	0.26	38	5.35	9
48	0.12	38	5.4	..

2.—Influence of surface contact.

According to the Henry-Dalton law, oxygen will displace carbon dioxide in water, that is, oxygen will "wash it out" of water if opportunity be given. This exchange of gases is promoted by contact with rough surfaces.*

Faraday has shown that oxygen and other gases are condensed on the surfaces of solid bodies.

Dunbar and Kryck† have given examples of how an intermittent filter effects an exchange of gases. During their experiments with intermittent filters, it was observed that directly after an idle period the amount of dissolved oxygen in the filter effluent was more and the amount of carbon dioxide less than in the influent, but toward the end of the period of operation the oxygen almost disappeared from the effluent, while the carbon dioxide increased in amount. The explanation is that the oxygen is condensed on the surfaces of the filter material during the idle period. Then the filter is put into service, and the water seizes upon the stored oxygen until the supply is exhausted; meanwhile the filter material absorbs carbon dioxide from the

*Piefke, *loc. cit.*

†*Loc. cit.*

water until it at last becomes saturated. At such times the effluent often contains more carbon dioxide than the influent. A short period of rest suffices for the oxygen of the air to displace the carbon dioxide absorbed by the filter during operation.

Schmidt and Bunte* have also shown that the removal of carbon dioxide is aided by a multiplicity of contact surfaces. They filtered a water, after various periods of standing in contact with air, through filter paper and new, pure, quartz sand, respectively. Before treatment it contained 9.5 parts of iron and 307 parts of free carbon dioxide per million and 4.13 cu. cm. of dissolved oxygen per liter.

TABLE 10.—Influence of the Presence of Sand on the Speed of Precipitation of Iron From Water.

Elapsed time since the beginning of reaction, in hours.	Iron found in the solution, in parts per million.	Free CO_2, in parts per million.	Oxygen, in cubic centimeters per liter.	K
WITHOUT SAND:				
0	9.5	307	4.13	22
0.25	9.0	304	4.87	15
0.75	8.5	278	5.2	12
1.25	8.2	184	5.24	10
1.75	8.0	146	5.4	13
2.25	7.5	115	5.61	13
3	6.5	75	5.65	17
5.14	3.8	45	5.93	22
6.5	2.2	39	6.05	..
WITH SAND:				
0	9.5	307	4.13	74
0.25	7.9	181	4.76	39
0.75	7.1	101	5.08	30
1.25	6.5	70	5.2	25
2.25	4.7	47	5.4	42
4.75	1.32	27	5.94	68
6	0.16	12	6.0	..

The effect of contact with sand on the speed of reaction is very noticeable. The value of K when sand was present was about three times as great as when it was absent.

Iron exists in water in company with acids other than carbonic, for example, hydrochloric, nitric, sulphuric, etc. The expression "in company with" rather than "combined with" is more in accordance with modern chemistry and engineering, and is used purposely. Were a ferruginous water a concentrated solution, a different idea might be

Loc. cit.

entertained, but where the dilution is so very great, the greater part of the iron is in the form of the hydrate, positive ions accompanied by acids—negative ions. Therefore, ground-waters are solutions of iron and acids, rather than solutions of iron salts. Waters containing hydrochloric and sulphuric acids and little alkali are difficult to purify because the presence of acid prevents hydrolysis, and thus checks the reaction.* Unlike carbon dioxide, these acids remain in solution and are not removed by aeration. The iron cannot be completely removed from waters containing free acid without the addition of an alkali.

The converse is also true, namely, the presence of an alkali, especially a caustic alkali, greatly favors the reaction, because it introduces hydroxyl (OH) ions, the excess of which hastens the action between the ferrous hydrate and the hydroxyl ions already present in the water.

It should be borne in mind that most natural waters are alkaline, and that the influence of free mineral acid is largely of theoretical interest.

The Precipitation of Oxidized Iron.—When iron oxidizes and precipitates it becomes iron hydrate, that is, iron-rust plus water. The particles may be so fine, however, that they remain in colloidal suspension indefinitely; in fact, this colloidal suspension is one of the transition stages between dissolved iron and precipitated iron-oxide sludge. The passing out of the colloidal stage is called coagulation. As coagulation begins, the fine particles attract and adhere to one another to form aggregates. These aggregates become large enough to be precipitated by gravity, and subside. Meanwhile they attract other aggregates until the liquid is filled with visible flocs of slowly subsiding ferric hydrate. This process is not instantaneous; it may be finished in a few minutes or it may require months, according to the character of the water under consideration; and the aim of engineering practice is to reduce the time to a minimum.

Factors Which Influence Coagulation.

W. Spring† has expressed the opinion that the electrical forces which hold iron in solution must be neutralized to cause its precipita-

* See p. 134.

†*Recueil des Travaux Chimiques des Pays-Bas et de la Belgique*, 19, 204-230 (1900).

tion. Without elaborating this statement it may be said that among the conditions which influence the coagulation and precipitation of iron hydrate are the following:

Presence of electrolytes;
Presence of alkalis;
Agitation and friction;
Contact with filtering material or precipitated iron hydrate;
Temperature;
Presence of humus compounds;
The relative concentrations of positive and negative suspended colloids, respectively.

Presence of Electrolytes.—If a weak solution of common salt be added to a colloidal suspension of iron hydrate in pure water, the hydrate coagulates in a brief time. This is because electrolytes precipitate colloids from colloidal suspensions. To understand this phenomenon it is necessary to consider that salts do not exist as such in aqueous solutions, but they are dissociated more or less completely into their component parts which are called ions. The force which causes this dissociation is an electrical one, the reverse of the well-known technical electrical process for transforming common salt into its constituents, namely, sodium (hydrate) and chlorine (gas), where the sodium ion in the solution migrates with the current to the negative pole; the chlorine ion against the current to the positive pole.

Likewise, calcium carbonate ($Ca\ CO_3$) in solution partially dissociates into calcium (Ca) and carbonic acid (CO_3), and magnesium sulphate ($Mg\ SO_4$) into magnesium (Mg) and sulphuric acid (SO_4). This explanation is according to Arrhenius's Theory of Electrolytic Dissociation. Ions, like suspended colloids, are of two kinds, namely, positive and negative, and it is customary to speak of the "electric charge" of an ion—that is, a positive ion as carrying a positive charge and a negative ion a negative charge.

The important fact in this connection is that the positive ions are mainly responsible for the precipitation of negative colloids and *vice versa;* thus it is the chlorine ion in common salt which mainly effects the precipitation of colloidal ferric hydrate. The chlorine ion carries a negative, the colloidal ferric hydrate a positive charge.

An example of the precipitation of negative colloids by electrolytes is the formation of bars at the mouths of rivers carrying colloidal

clay in suspension. While the formation is due in a large degree to the checking of the velocity of the current, which causes the coarser particles to precipitate, it is the presence of electrolytes in the sea water which causes the precipitation of the extremely finely divided clay. These facts are well established; the mechanism of coagulation has not yet been completely elucidated, although chemists have advanced interesting hypotheses.

The importance of the law of electrolytic dissociation in this connection lies in the fact that, in a suspension of colloidal ferric hydrate, the speed of precipitation, other things being equal, is proportional to the cencentration of the negative ions in the ground-water under consideration. The precipitation is little accelerated, if at all, by the presence of positive ions; for example, it is the amount of the carbonic acid ion in calcium carbonate, not the amount of the calcium ion—the number of the chlorine ions in magnesium chloride—not the amount of the magnesium ion—which does the work. In the latter case the magnesium ion is charged with positive electricity to double the extent that the chlorine ion is with negative electricity, because one magnesium ion is equivalent chemically to two chlorine ions.

Freundlich* has determined the relative amounts of various electrolytes required to coagulate colloidal ferric hydrate, as follows:

Salt.	Coagulation concentration, in milli-equivalents per liter.
Potassium sulphate	0.41
Magnesium "	0.93
Sodium chloride	9.3
Barium "	9.6
Potassium nitrate	11.9

This shows that, other things being equal, waters containing sulphates precipitate iron much more rapidly than those containing the same amounts of chlorides or nitrates.

Schmidt and Bunte† have made experiments to determine the effect of various salts on the speed of precipitation of iron from iron-containing waters, and have obtained results in accordance with Freundlich's observations. For example, they found that carbonates

Zeitschrift für Phys. Chem., 44, 135 and 151 (1903).
†*Loc. cit.*

aided precipitation more than sulphates, and sulphates more than chlorides. This explains why the waters of the North German plain, containing much carbonate and considerable sulphate, are more readily purified (leaving the effect of vegetable matter out of consideration) than the soft waters of the New England coast.

Presence of Alkalis.—After the iron is oxidized, alkalis assist the precipitation of iron as do other electrolytes, by increasing the concentration of negative ions.

Agitation and Friction.—Many observers have noticed that if one of two bottles of an aerated, iron-containing ground-water be shaken, it will deposit iron more quickly than the sample which is not shaken. Perhaps shaking serves to bring the particles together just as the churning of cream causes the globules of fat to separate from the milk. If inert suspended matter be present during the shaking, the precipitation is hastened. Likewise the passage, through a layer of clean, pure, quartz sand or glass beads will often cause the sudden precipitation of the iron.

Contact with Filter Material or Precipitated Iron Hydrate.—It has been the common belief of Piefke and many others that it is the contact with filtering material and not the size of the same which precipitates and retains the ferric hydrate; for example, many European deferrization plants have filtering layers composed of sand which is coarser than 1 mm.; a material seemingly coarse enough to pass quite coarse precipitates. This belief is tenable. The vital thing is multiplicity of surface contact. In this connection may be mentioned the well-known efficiency of gravel-roughing filters* for the removal of colloidal suspended clay from the waters of muddy rivers.

If a little precipitated ferric hydrate be added to a sample of water just about to precipitate its iron, the action will be accelerated to a marked degree. This is another reason why filters are more efficient after the filtering material itself has acquired a layer of iron hydrate than before. The action of the iron hydrate has been shown by Dunbar and others to be purely a physical one. It is really a porous, spongy mass which increases the effective contact area exposed to the water passing through the filter; or if added directly to a sample of water, it exposes a very large surface to the water and hastens the

*Reports of Water Supply Department of Philadelphia, Pa.; Ad. Kemna, *Engineering News*, 59, 328.

precipitation in this way. Again, one may conceive of it as a "starter," that is, multitudinous nuclei around which the fine particles of suspended colloidal ferric hydrate cluster, thus helping to neutralize the electric charges which keep the hydrate in suspension.

Temperature.—Graham and others have stated that temperature affects the coagulation of colloids in concentrated solutions only.

Schmidt and Bunte* have observed that while an increase in temperature accelerates the liberation of carbon dioxide, and therefore increases the speed of oxidation, the direct effect of temperature on the precipitation of iron from waters having the same amounts of carbon dioxide could not be determined. At Knoxville, Tenn., the writer has observed that the coagulation of the finely divided clay in the Tennessee River water by sulphate of alumina is much more easily accomplished in summer than in winter; still, other conditions, such as the character of the suspended matter and the concentration of salts (electrolytes) in the water, may not be constant throughout the year, and may offset the apparent effect of temperature.

Doubtless ferric hydrate will coagulate a little faster at higher than at lower temperatures, but this effect is too slight in the case of a dilute solution of fairly uniform temperature, like ground-water, to be of any considerable importance from an engineering standpoint.

Humus Compounds.—Humus is the active principle of leaf-mould, and the name has been given to a mixture of various substances of indefinite composition which have resulted from the decomposition of organic matter, in the partial or complete absence of oxygen. They may be considered to be the products of Nature's septic tank. It is necessary to distinguish the main classes of humus matter from one another; even in recent literature, statements have been made which show a lack of appreciation of any difference in humus compounds. Some of these bodies are albumens; some are gums; some are organic acids; some are acids in combination with calcium, magnesium, iron, etc.; and some of the bodies combine with iron and form a brown-colored compound. From a water-purification standpoint, however, there are three classes, namely, those in solution, those in colloidal solution, and those in colloidal suspension.

The first class probably affects the deferrization process but little. Not much is known of this class, and their existence is doubted by

Loc. cit.

many chemists. They may impart taste or odor to a water, which taste or odor can be removed by aeration, ozonization, or absorption.

The second class, humus matter in colloidal solution, is a great hindrance to the precipitation of iron. These gelatinous or gummy bodies are not precipitated by aeration. They remain in solution indefinitely until absorbed by suspended matter or by the action of filtering material, or until they are destroyed by bacterial action. What is worse, a very small amount of these gelatinous bodies will hinder the precipitation of a larger amount of iron. They are more apt to be present in seepage water from near the surface than in the dark brown water of deep wells, leading one to believe that the more recent the decomposition of vegetable matter, the larger will be the proportion of these humus bodies in colloidal solution. They yield readily to treatment with ozone.

The third class of humus matter is also important. It has been known for a long time that the coloring matter in the Dismal Swamp (Virginia) water when exposed to air would coagulate and precipitate spontaneously. Most of the surface water in the Bavarian forest has a brown color, but after a short run in the brooks and rivers it becomes perfectly clear.*

The writer has observed the same phenomenon in the Adirondacks. Such waters are apparently clear, but the coloring matter is really in colloidal suspension.

Recently, Wernike and Weldert† have shown that when the dark brown, Artesian well water from the vicinity of Posen (Table 11) is mixed with the iron-containing, shallow well-water supply of the city, the color and iron are precipitated immediately, enough oxygen being present to oxidize the iron. The water of some of the wells supplying Kiel contains both coloring matter and iron which when exposed to the air precipitate spontaneously.‡ The precipitate is in the form of dark brown, coarse flocs which contain humus matter and iron only. In this case, the different waters were originally in the ground in layers, and were mixed below the surface rather than above, as at Posen.

The Effect of the Relative Concentrations of Positive and Negative Colloids, Respectively.—The best explanation of the above-mentioned

*H. Blücher, "Das Wasser," p. 119.
†*Loc. cit.*
‡Professor Dr. B. Fischer, *Hyg. Rund.*, 17, 1089.

TABLE 11.

Proportions in Mixture.		Filtered Water One Hour After Mixing.					
Shallow well water.	Artesian water.	Clearness.	Appearance: Transparency, in centimeters.	Color.	Chlorine.	Iron. Fe_2O_3.	Oxygen consumed.
Ferruginous.	Colored.						
cu. cm. 900	cu. cm. 100	turbid	8	yellow brown	34	16.	40
800	200	slt. turbid	12	" "	48	6.	28
700	300	v. slt. turbid	15	yellow	68	2.1	15
600	400	clear	over 18	very slt. yellow	82	0.4	13
500	500	"	" 18	almost none	99	0.1	12
400	600	"	" 18	" "	112	0.1	12
300	700	"	" 18	" "	127	0.0	14
200	800	"	" 18	" "	148	0.0	23
100	900	"	" 18	very slt. brown	161	0.0	48
75	925	"	" 18	slt. brown	165	0.0	96
50	950	"	" 18	" "	171	0.0	98
25	975	"	" 18	dark brown	173		169
10	990	"	" 18	" "	175		207
Shallow well water				slt. yellow	18	18.	24
Artesian water				dark brown	178	0.9	246

precipitation phenomena is that the brown coloring matter is a negative, suspended colloid and the ferric hydrate a positive, suspended colloid; that is, their electric charges have opposite signs, and, when mixed in proper proportions in the presence of oxygen, precipitate one another, probably because the electric charges balance and neutralize. Whatever may be the explanation, it is well known that either the coloring matter or the colloidal ferric hydrate will stay in suspension in pure water indefinitely when kept separate, but that when mixed in certain proportions, they will mutually precipitate each other. From a practical standpoint, the proportions of the mixture may vary considerably without affecting the general result; that is, the line separating mixtures which will precipitate from those which within a reasonable time will not, is a broad one, more of a zone than a line, as the experiments, shown in Table 11, by Wernike and Weldert with Posen water will illustrate.

The coloring matter at Posen is derived from brown coal deposits which underlie the city and its vicinity. Weldert prepared colloidal suspensions of brown coal and ferric hydrate, respectively, and found that they mutually precipitated one another, as did the natural waters containing them.

Professor Fischer, of Kiel, could not cause the precipitation of colloidal ferric hydrate by solutions of peat. Apparently he did not distinguish the younger and fresher coloring matter in peat from that in brown coal. The former is probably in colloidal solution, and, therefore, hinders the precipitation of the colloidal suspensions of either ferric hydrate or color, which may be present.

The reverse of the above, namely, the use of colloidal ferric or aluminum hydrate for the removal of coloring matter from water and other liquids, has been practiced for centuries. Alum, which forms aluminum hydrate when added to colored alkaline water, is one example, and Proskauer's proposal to treat the dark brown deep-well waters of Germany with colloidal ferric hydrate, prepared by passing an electric current through iron plates immersed in the water, is another.

During the writer's experience at Reading, Mass., colloidal iron was added to the water with the hope that it would cause the precipitation of the organic matter, and thus permit the precipitation of the iron contained therein. The colloidal iron hydrate thus prepared did

combine with the organic matter, but no advantage was gained; indeed it was necessary to add enough iron hydrate to remove the organic matter by the absorbent action of a large bulk of precipitated hydrate. When this was done, the iron present in the ground-water could be precipitated, but under these conditions the filter clogged too rapidly for economical operation. The added colloid had the wrong sign for the removal of the iron and had little effect upon the organic matter, because most of the latter was not in colloidal suspension. Since the preparation of this paper was begun there has appeared a serial article by M. Henri Schwers, of the University of Liége, in which it is stated that this compound of iron and organic matter is also in colloidal suspension—an interesting fact, if true.*

Use of Ozone as an Aid to Deferrization.

Ozone is an active oxidizer and also causes the precipitation of iron from ground-water in a marvelous manner, first, by rapid oxidation of the iron; and, second, by the destruction of the organic matter in colloidal solution, which interferes with precipitation.†

Hitherto its cost has been prohibitive, but recent developments in France are so promising that it is probable that the cost will be reduced within practicable limits in the near future. Ozonized water, like aerated water, must be filtered before distribution.

Deferrization by Organisms.

Organisms grow in ferruginous ground-water the same as in surface water, but the usual absence of light favors the growth of a special group of fungi, the so-called iron bacteria. Among these are *Leptothrix ochracea, Crenothrix polyspora, Gallionella ferruginea, Clonothrix fusca, Anthophysa vegetans* (Müller), and *Actineomycetes.* Of these the more important are *Leptothrix, Crenothrix,* and *Gallionella.* These latter consist of a single row of cells surrounded by a gelatinous sheath. The iron deposits on the sheath, and, in the presence of oxygen, the organisms appear like irregular threads of ferric hydrate, at the ends of which are the colorless young cells partly surrounded with their nearly colorless sheath. Unlike algæ or diatoms they contain no chlorophyl. They grow in the absence of light; and apparently

Révue d'Hygiène, 30, 108.

†G. A. Soper, M. Am. Soc. C. E., *Engineering News,* 42, 250.

they grow best in the presence of iron and small amounts of organic matter and oxygen. They are very hardy and can survive in the depths of the earth, from which they can get into good well-water.

This class of organisms undoubtedly does cause the precipitation of iron from ground-water, but it is natural to ask whether the iron is a food for the growth of the fungus and is subsequently excreted by it, or whether it acts like finely divided, gelatinous, suspended matter and causes the precipitation of the iron by contact and absorption.

M. Schwers has studied the formation of natural ochres in Belgium, and his results are most interesting and instructive.* He examined 208 deposits of different colors and structures, all mixed with more or less organic débris, bacteria, diatoms, filamentous bacteria, etc. He found ferruginous bacteria in 160 of the 208 deposits studied. Of these, 51 contained pure cultures of *Leptothrix,* and 18, pure cultures of *Gallionella. Crenothrix* was not found. Besides the ferruginous bacteria, green algæ were found in 34 and diatoms in 41 deposits; while 21 deposits contained only green algæ and 22 only diatoms. It is quite evident from these observations that organisms other than filamentous bacteria and organisms whose growth is surely independent of the presence of iron, play parts in the deposition of iron from water containing it. M. Schwers believes, as the result of his observations, that the deposits of iron on the sheaths of these organisms is purely mechanical, the result of absorption and surface contact.

In May, 1904, the writer made observations at Reading, Mass., where the gallery water was treated by passing it through a box containing iron nails and thence directly to a sand filter with wooden sides. The filter had an area of 18 sq. ft., and the rate of filtration was 6 000 000 gal. per acre per diem. The period of contact between the water and the metallic iron was at least 1 min. The water was not aerated, although it contained about 1 part of oxygen per million. The filter removed the iron almost completely. Examination showed that the sides of the box containing the iron, the wooden walls of the filter, and the surface of the sand were covered with a growth of *Leptothrix ochracea,* in some places 2 in. thick An aerator was interposed between the box containing the iron and the filter. On May 6th, with the aerator in service, the water in the filter contained 5.27 and the

*Révue d'Hygiène, loc. cit.

filtered water 1.18 parts of dissolved oxygen per million; soon, however, the growth of *Leptothrix* disappeared, probably because of the excess of oxygen present, and the efficiency of the filter declined rapidly. On May 28th, the well-water contained 1.5 parts and the filtered water 1.6 parts of iron per million. The amount of carbon dioxide during these experiments was about 20 parts per million, on the average. Microscopical examination of the *Leptothrix* and inspection of the surface of the sand showed that most of the iron had adhered to the *Leptothrix*.

Without going too deeply into the details, it may be stated that no one has yet succeeded in growing any of these organisms in the total absence of iron, and there are analogous organisms (*Beggiatoa*) which precipitate sulphur from ground-water containing it. On the other hand, there is an apparent precipitating effect independent of the biology of the organism and due to the physical action of the gelatinous sheaths of the organisms.

It is also possible that the same organic matter which holds the iron in suspension is a food for these bacteria, and that the removal of the food permits the precipitation of the iron. If this be true, precipitation would take place, very logically, near or on the organisms.

Historical.

The difficulties experienced with waters containing iron and manganese have been already outlined. The whole object of the deferrization processes is to cause the oxidation and precipitation of these troublesome elements before the water enters the distribution system, and not afterward in the service pipes and on the laundered fabrics belonging to the consumer.

The processes which have been evolved are based upon very simple phenomena, and most failures have been due to the neglect of simple, elemental principles. The iron which appears at the surface of the ground in a soluble form must be converted into the insoluble form and be precipitated. The reagent used for this purpose is the oxygen of the air. The presence of carbon dioxide and gelatinous organic matter interferes with the oxidation and precipitation of the iron, while the presence of suspended matter and certain salts furthers it. In certain cases, simple aeration, subsidence, and filtration fail to remove the iron within a reasonable period. In such cases the water may be treated with a coagulant to hasten the precipitation.

To the writer's knowledge, the history of the development of the deferrization processes has never been written in English. Professor Dunbar, of Hamburg,* Baurath A. Thiem, of Leipsic, with Professor Fischer, of Kiel,† Director L. Darapsky,‡ and M. Henri Schwers,§ have given descriptions of many of the devices which have been used in Europe, and which, with many other published articles and the writer's observations, form the basis for the following statements.

Salbach, of Dresden,|| must be credited with the first successful process on a large scale, although it was known for centuries that certain ground-waters could be freed from iron by allowing them to stand for a time in contact with the air.

In 1868, Salbach built at Halle an aerator and filter which produced a "perfectly clear and brilliant" effluent. The aerator was filled with coarse gravel, the filter with sand. Salbach's process, however, was not widely known and was never put into practice, although it is claimed by some that he advised the Charlottenburg Water Company, when the Teufelsee works were built in 1873-74.

In 1880, Anklam¶ aerated the ground-water at Tegel, and was able to remove the iron therefrom by subsequent filtration, while, without aeration, the iron ran through the filter. Anklam's aerator consisted of a step-like cascade built of wood, over which the water fell. Its total height was 2 ft., and it discharged directly upon the filter. In 1882, Wingen, without knowledge of Anklam's work, accomplished a similar result at Golgau; while Oesten and Proskauer,** from 1886 to 1890, conducted successful experiments with the Berlin ground-water, spraying the water from a height of 2 m. upon the water surface of a coarse gravel filter which removed the iron satisfactorily. In 1891, Piefke†† published results of experiments at the Straulau works, in Berlin, where he used a coke instead of a gravel aerator. (See Fig. 5.)

Afterward, Wellman‡‡ used brick filling for the aerators at Charlottenburg, and, more recently, Beer§§ and others have used superimposed bundles of wooden slats with equally good results, notably at Berlin.

Zeitschrift für Architectur- und Ingenieurwesen, 1898.
†*Deutsche Vierteljahresschrift für öffentliche Gesundheitspflege*, 29, No. 1.
‡*Gesundheits-Ingenieur*, 1904.
§*Révue d'Hygiène*, 30, 11, *et seq.* (1908).
||"Bericht über die Erfahrungen bei Wasserwerken und Grundwasserversorgungen," Dresden, 1893.
¶*Schillings Journal für Gasbeleuchtung und Wasserversorgung*, 35, 517.
**Schillings Journal für Gasbeleuchtung und Wasserversorgung, 34, 35.
††*Schillings Journal für Gasbeleuchtung und Wasserversorgung*, 34, 56.
‡‡*Gesundheits-Ingenieur*, Vol. 17.
§§*Schillings Journal für Gasbeleuchtung und Wasserversorgung*, 46, 681.

All these processes consist of aeration followed by filtration. Sometimes a short period of sedimentation precedes the filtration.

Meanwhile another class of purification plant was being introduced, namely, the so-called "closed installation," first introduced into Germany, in 1897, by H. von der Linde and Dr. C. Hess, at München-Gladbach.* This system did not use aeration. It consisted of closed tanks or pressure filters filled with red beechwood shavings, which latter were impregnated with tin oxide. It was alleged† that the tin oxide furnished the oxygen necessary for the precipitation of the iron. These plants were quite extensively introduced, notably at München-Gladbach and at Düsseldorf.

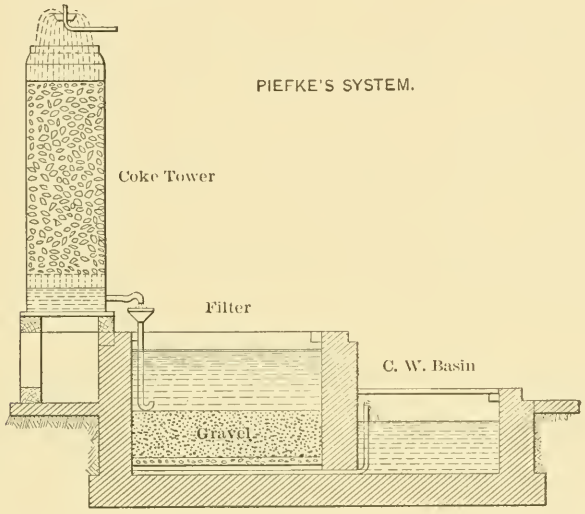


FIG. 5.

In 1902, Dr. Helm, of Danzig, replaced the tin-impregnated shavings in the von der Linde and Hess filter with magnetic iron ore. He obtained equally good results and without the danger of any increase in bacteria due to fermenting shavings. In 1903 Hertzberg, near Berlin, obtained corresponding results with a similar filter containing ordinary sand, and in the same year Director Bock, of Hanover, installed the new plant for that city in which untreated shavings were

Deutsche Bauzeitung, 32, 593.

†Schindowski, in a dissertation (Leipsic, 1900, p. 24), proved that all closed filters fail to remove iron when oxygen is absent from the unfiltered water, regardless of the presence of tin or other oxides.

used, which, however, were prevented from becoming contaminated with bacterial growths by frequent sterilization with live steam.

In America, between 1890 and 1896, the Continental and other filter companies introduced several pressure filters, notably at Asbury Park, N. J. These filters consisted of pairs of closed tanks, the first filled with sand, the second with bone charcoal. At first the plants were installed without any provision for aeration other than that supplied by leaky pistons and suction mains and by the air which was used to agitate the filter material during washing. Another example is the plant at Atlantic Highlands, N. J. Experiments with the Asbury Park plant in May, 1895, by Dr. T. M. Drown showed that without aeration iron was incompletely removed after the capacity of the bone charcoal for absorbing iron had been exhausted, and aeration by a Pohle air-lift was accordingly introduced with good effect.

In 1896 Mr. H. W. Clark, Chemist of the Massachusetts State Board of Health,* made experiments with the water at Provincetown, Mass., a water which contained a great deal of organic matter and with which a sand filter operated fully as efficiently without as with thorough aeration. Mr. Clark found that, by passing the water through a filter filled with bits of iron, "the ferrous hydrate formed by the water and the iron filtering material would unite and effect a removal of the iron in the water to a remarkable degree, when after such treatment the water was passed through the sand filter." He also succeeded in effecting the same result by passing the water through fine coke which contained considerable iron. Mr. Clark believed that the almost complete coagulation of the iron during the latter experiment was due to the chemical action caused by the metallic iron contained in the coke, as well as to the mechanical action of the rough particles of the coke itself.

Mr. Clark also experimented with the use of potassium permanganate as an aid in the deferrization of the Provincetown water. The results were satisfactory; but the cost of the chemical prevented its adoption and practice. In addition to the experiments at Provincetown, Mr. Clark† made other experiments with the ground-water supplying Watertown, Marblehead, and Reading. The iron from the Marblehead water, as well as the color, was almost completely removed

Journal, New England Water-Works Assoc., 11, 277.

†Report, Mass. State Board of Health, 1899, pp. 537 to 553.

by simple aeration and filtration, even at rates of filtration as high as 15 000 000 gal. per acre per diem, while the effluent from the experimental filters at Watertown, even with long-continued aeration, always contained more than 0.2 part of iron per million. Mr. Clark attributed the difference to the presence of organic matter in the Watertown water, which held the iron in solution. It is an interesting fact that Mr. Clark notes that "better results were obtained in subsequent filtration by aerating in the manner described [simple spraying*]—which required but a few seconds—than by drawing air through the water for a much longer period." Experiments at Reading showed that lime would assist the removal of iron.

During 1905-1906, the writer made experiments with the Reading, Mass., water, treating it with metallic iron, first in a revolving drum filled with iron (Anderson process), and afterward, in the colloidal form (hydrate) by iron-plate electrodes immersed in the water and through which an electric current was passed. Although this process removed the iron in a fairly satisfactory manner, it was not recommended, both on account of its cost and because the treatment with clay and sulphate of alumina was more practicable under local conditions. Later experience leads the writer to believe that at certain times it would be impracticable to coagulate the iron by such treatment.

In 1898 Dunbar and Kryck† suggested intermittent filtration through coarse sand, especially where the available head is low, thereby avoiding double pumping, or where (as in small plants) the filter can be filled only occasionally. They believed that this type of filter could be used much more frequently than had been the case hitherto. In operation it is not filled above the surface of the sand, and special provision for aeration is unnecessary. It is especially adapted for use on small estates, in schoolhouses, etc.

In addition to the oxidation processes, there have been some plants built where chemicals are used to precipitate the iron. In 1891 Herr O. Kröhnke‡ added lime or sometimes lime and an iron salt to water and afterward removed the precipitated iron by a pressure filter.

In 1895, The Cumberland Manufacturing Company, of Boston, advised the Town of Reading§ to aerate the water from the filter gal-

*Report, Mass. State Board of Health, 1899, pp. 537 to 553.
†*Schillings Journal für Gasbeleuchtung und Wasserversorgung*, 40, 548.
‡Dunbar, *Zeitschrift für Hygiene und Infektionskrankheiten*, 22, 118.
§Bancroft, *Journal*, New England Water-Works Assoc., 11, 294.

leries and, after the addition of lime and sulphate of alumina, to filter the same. The advice was adopted, and, in 1894, a "Warren" filter plant was installed. This was operated as designed until April 19th, 1906, when clay suspension was substituted for lime. A smaller plant, using lime and sulphate of alumina, was built at Keyport, N. J., at about the same time.

Recently, R. Gans* has suggested calcium aluminum silicate or artificial zeolite as a precipitant for iron-containing water. This is marketed under the trade name of "Permutit." The cost of the chemical, however, has been too high to justify its use in practice.

The most interesting recent development has been the discovery by Professor Wernike and Director Mertens, at Posen, Prussian Poland,† that a mixture of the iron-containing, shallow-well water (purified only with great difficulty by aeration and filtration) with a dark brown, deep-well water, could be filtered rapidly through sand, and that the effluent would be free from both iron and coloring matter, which precipitated one another when the waters were mixed. This process has been adopted by the City of Posen, and the plant is to be installed immediately, with Jewell mechanical filters to remove the precipitate.

Since the preparation of this paper was begun, M. Henri Schwers‡ has suggested the use of ferric chloride as a coagulant. Kröhnke had previously used ferric chloride, but in conjunction with lime.

Table 12 summarizes the history of the various processes.

European Practice.

The writer has made frequent mention of European practice, especially of that which relates to the arrangement and type of works. It now remains to discuss some special features connected with their efficiency.

In North Germany and the Low Countries, generally speaking, the cities with ground-water supplies, built upon the alluviums of the various rivers such as the Oder, the Vistula, the Elbe, the Weser, and the Rhine, are provided with deferrization plants. Many of these cities, especially those in Germany, have been mentioned. The

* *Chemiker Zeitung*, 1907, p. 355.

† *Mitteilungen a. d. Königl. Material Prüfungsanstalt*, 1907, No. 8.

‡ *Révue d'Hygiène*, 30, 1908.

ground-water supplies of Berlin and suburbs are good examples of German practice, as illustrated by Table 13.

TABLE 12.—Development of the Deferrization Processes.

Process.	Inventor and system.	Date of introduction.
Aeration followed by filtration through fine gravel or coarse sand..	Salbach (Gravel aerator)	1868
	Anklam (Cascade aerator)	1880
	Oesten (Spray aerator)	1890
	Piefke and Proskauer (Coke aerator)	1891
	Wellman (Brick-filled aerator)	1894
	Beer and Thiem (Wooden-slat aerator)	1902
Filtration without aeration by pressure filters.	American pressure filters (Sand and bone charcoal)	1894
	von der Linde and Hess (Tin oxide-impregnated shavings)	1897
	Helm (Danzig) (Magnetic iron ore)	1902
	Bock (Hanover) (Plain shavings)	1903
Treatment with metallic iron and filtration.....	Clark (Filtration through fine coke or iron chips)	1895
	Town of Reading (Electrolytic iron)	1904
Intermittent filtration through coarse sand...	Dunbar and Kryck	1898
Chemical treatment and rapid filtration.....	Kröhnke (Lime without aeration)	1891
	Cumberland Mfg. Co. (Reading) (Lime and sulphate of alumina with aeration)	1894
	Weston (Clay and sulphate of alumina)	1906
	Gans (Filtration through calcium aluminum silicate)	1907
	Schwers (Ferric chloride, slow filters)	1907
Precipitation by mixture of iron-containing water with colored deep-well water, followed by rapid filtration.....	Wernike and Mertens (Posen)	1906

TABLE 13.—Deferrization Plants in Berlin and Suburbs.*

Municipality.	Consumption, in U. S. gallons per diem.	System.
Adlersdorf	715 000	Brick-filled aerator and sand filter.
Berlin (five works)	over 5 300 000	Wooden-slat aerator and sand filter.
Boxhagen-Rummelsbrug	1 375 000	Brick-filled aerator and sand filter.
Charlottenburg (four works)	6 000 000	" " " " "
Fürstenwalde-a-Spree	192 000	von der Linde and Hess.
Hohen-Schönhausen	31 600	Oesten.
Lichtenburg	2 200 000	Piefke.
Nauen	130 000	Oesten-Piefke.
Nieder-Schönhausen	658 000	Coke aerator and sand filter.
Pankow	823 000	O. Smreker.†
Potsdam (part)	.....	Thiem.
Reinickendorf	1 238 000	O. Smreker.†
Spandau	3 020 000	Aerator and sand filter.
Tegel	3 565 000	" " " "

*Data furnished by Prof. Thum.

†Pressure filters.

Most of the other suburbs obtain water from one of the Berlin or Charlottenburg works. During 1905, the former city supplied 735 000 U. S. gal. daily, on an average, to these suburbs.

In Holland the water from the sand dunes is often delivered to fine sand filters by gravity. This water is apt to contain iron, but in many cases aerators are not necessary; the filtered water is excellent. Humus matter is the cause of most of the trouble with the Dutch dune-water supplies.

The plant at Hanover operates with a water containing an average of only 0.5 part of iron per million, also traces of manganese. The maximum amount of iron and manganese is about 0.7 part per million. Formerly, the works were operated without filters; but since 1904 the present installation has been in service. The filter plant, Plate II, consists of 30 cylindrical units, each 2 m. (6.6 ft.) deep, with diameters of 1.5 m. (5.0 ft.) at the top, and 1.35 m. (4.5 ft.) at the bottom. They are filled with red-beechwood shavings. These shavings are about 0.04 in. thick, 0.2 in. wide, and average about 1 ft. in length. The rate of filtration is 4.8 vertical in. per minute, or about the same as that used with American rapid filters. No aeration is provided except that which unavoidably takes place through joints in the suction pipe, in the collecting well, and through the piston rod glands. The filters were provided with apparatus for washing under pressure; this was found to be too expensive, however, and, at present, the shavings are removed from the filters, washed in masonry tanks, and then replaced in the filters. Three of the thirty tanks are cleaned daily; that is, each unit operates for ten days between cleanings. The writer saw one tank opened, and observed that the iron hydrate was quite well distributed through the mass of shavings, although it had collected most abundantly at the top. The freshly opened filter emitted an odor characteristic of decaying wood. This odor must be more marked in summer. After cleaning, the shavings are sterilized by steam; otherwise, the disagreeable odor would develop much sooner and would make it necessary to clean the shavings more frequently. The filters do not remove all the iron, and the deposit in the water-tower contains manganese.* The writer's observation leads him to believe that it is the light task rather than the suitability of the design, which makes it possible to furnish a reasonably satisfactory

* See p. 173.

water to the city. The aeration is accidental only, although oxygen is absorbed by the shavings during washing, and perhaps at other times.

The pressure-filter plant at München-Gladbach is similar to that at Hanover. Fig. 6 may help to explain this type of filter more clearly.

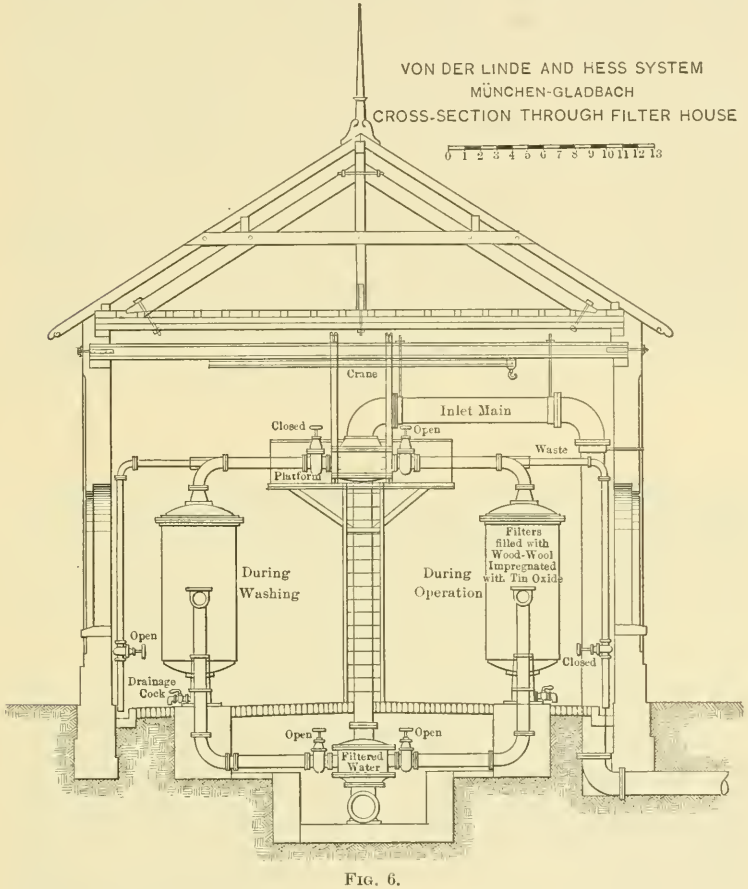


FIG. 6.

This plant has a nominal capacity of 76 500 gal. per hour. It consists of 11 filter tanks arranged in a circle; each tank is 4.8 ft. in diameter and 8.3 ft. high. The ground-water contains 2.3 parts of iron per million, and it is necessary to wash each filter thrice daily. Every two months the filter material is removed and cleaned in a washing-machine. Each filter holds 3 300 lb. of shavings impregnated

with tin oxide, and 550 lb. must be added after two months' use to make up for the shrinkage. The amount of wash-water is about 15% of that filtered, and the loss of head is about 10 lb.

The experience at Fürstenwalde-a-Spree is interesting. This plant also consists of pressure filters, after the von der Linde and Hess system, taking water directly from wells. The four filter tanks are filled with noodle-like shavings, and aeration is effected by admitting air into the suction pipe. After aeration, the water goes directly to the filters, and consequently the period of coagulation is very short. The works were put in service in 1905. At the beginning, the ground-water contained 2.0 parts of iron, but, in 1908, it contains only 1.4 parts of iron per million. Manganese is not present. In 1905 the amount of iron in the filtered water was 0.2 part per million; since then, the consumption has doubled and has reached about 317 000 gal. per diem. The iron in the effluent, however, has arisen to 0.3 part per million, and some of it precipitates in the water-tower and also in the distribution system. The rate of filtration is twice as high as that used for rapid filters in America, and when more than 265 000 gal. per diem are filtered, it is necessary to wash the filters twice a day. Improvements are suggested; one proposition is to bore the wells deeper; another is to install preliminary aerators or filters.

The experience at this plant illustrates very clearly the importance of the time element in the process. When more time elapsed between the wells and the filters, the iron was removed in a satisfactory manner. Recently, however, there has been a reduced efficiency.

The deferrization plant at Kiel* consists of aerator and filter, of which the aerator alone will be described. The water, 3 750 000 gal. per diem, is distributed uniformly over the surface of coke aerators which are 4.6 ft. square on the surface and 10 ft. thick. Eight aerator units are placed in a building immediately over the sedimentation basin. The coke rests upon an iron grating which admits air beneath the coke; numerous openings in the wall of the aerator also admit air. A channel, 2 ft. wide, delivers the water into an octagonal, cast-iron distributor from which it flows over eight weirs into the several compartments of the aerator. Each compartment has a main distribution channel from which leads a transverse gutter, and from this the water falls upon a sheet of corrugated metal, the corrugations of which are at

*Schillings Journal für Gasbeleuchtung und Wasserversorgung, 40 (1896).

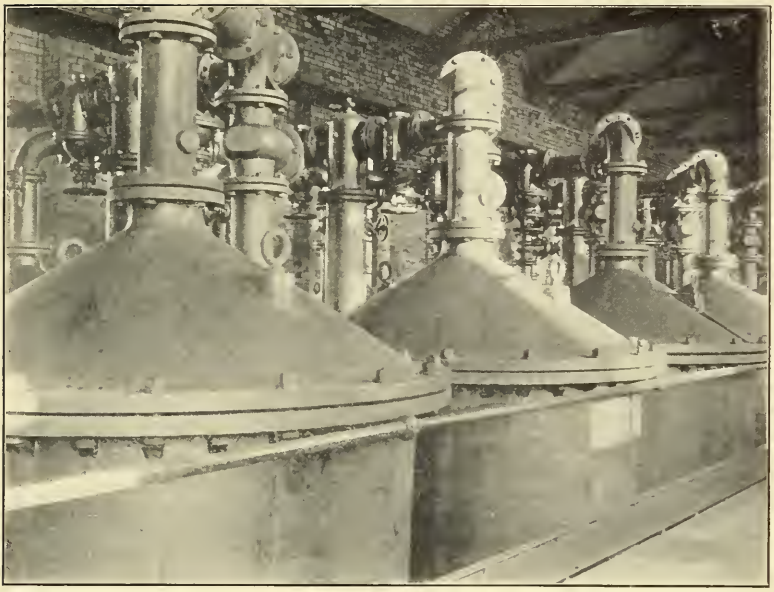
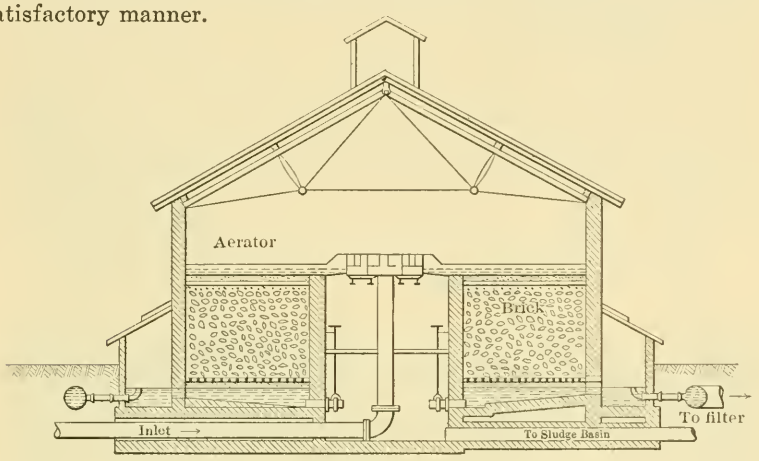


FIG. 1.—PRESSURE FILTERS, HANOVER, GERMANY.

FIG. 2.—APPARATUS FOR WASHING AND STERILIZING SHAVINGS, HANOVER, GERMANY.

right angles to the transverse gutter. Both the gutters and the furrows in the corrugated metal are pierced with holes. This arrangement effects a very uniform distribution of the water over the surface of the coke. A similar arrangement is used in connection with most of the aerators of the tower type in Germany.

The sedimentation basin beneath the aerator is provided with baffles, and the water delivered to the filters contains only from 15 to 25% of the initial amounts of iron. When the well-water contains 4 parts of iron per million, it is necessary to clean the aerator after 26 500 000 gal. have been passed through it. This plant works in a satisfactory manner.



CHARLOTTENBURG

FIG. 7.

The Charlottenburg aerators are filled with brick instead of coke. Fig. 7 shows the general arrangement of this plant.

In Germany the usual rate of application to the aerator is 16.6 cu. ft. per square foot per hour, although at Stargard, where the final filtration is quite rapid, this rate was found to be about 20% too high, and at Worms much higher rates are used.

The rate of filtration through final filters varies from 3 000 000 to 20 000 000 gal. per acre per diem. At Stargard it is 15 200 000 gal. per acre per diem, while, at Berlin, rates from 3 000 000 to 5 200 000 gal. per acre per diem are used. At Müggelsee a filter operated 417 days between scrapings, about twice the maximum period ever obtained when filtering surface water at half the rate.

The new filters at Hamburg, Fig. 8, are interesting in that they are exposed to the air as much as possible, especially during the idle period.* The water is distributed upon the surface of a coke aerator about 9 ft. thick, whence it passes through the coke into a small basin and thence through spray nozzles to the filters. The sand layer is only about 8 in. thick, and is composed of sand with grains 1 mm. in diameter, much finer material than is generally used in Germany. The surface of the sand is hardly covered with water, and during the idle periods the filters are drained. Ample aeration is provided, and the results have been excellent. The loss of head in the whole plant is about 22 ft.

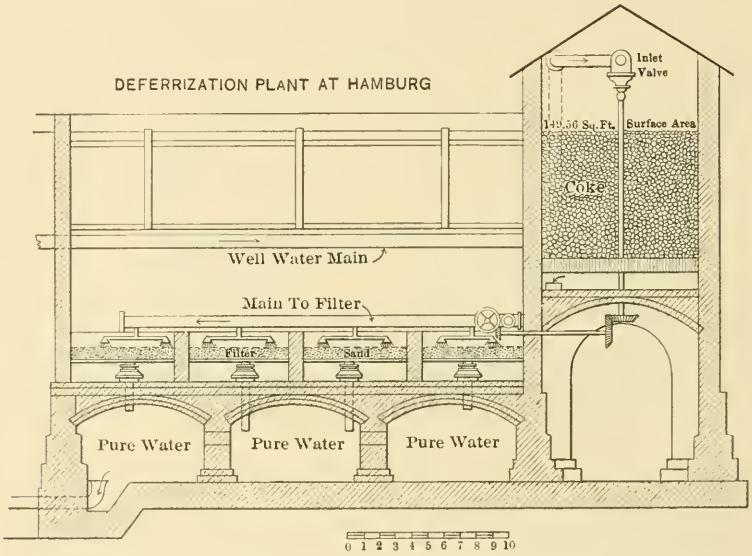


FIG. 8.

It has been customary to use quite coarse material for final filters. This has the advantage of causing the precipitation of the iron throughout the whole mass of filter material, and allows a far more economical operation of the plant. On the other hand, these filters "break" quite frequently, and, where the filtered-water basin is small, may cause turbid water to be distributed; this is especially noticeable just before cleaning. This difficulty does not occur where finer sand is used, as at Berlin.

Schillings Journal für Gasbeleuchtung und Wasserversorgung.

FIG. 1.—COVERED FILTERS AND PUMP-HOUSE, BERLIN, GERMANY.

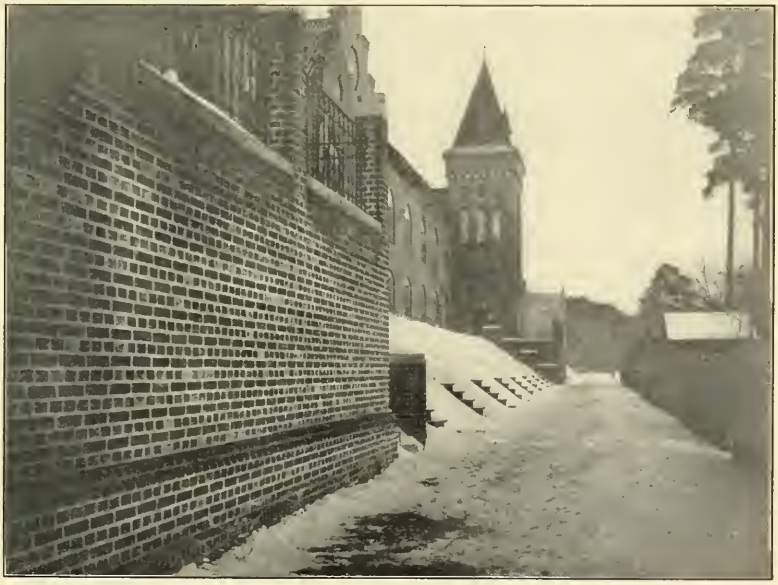


FIG. 2.—AERATOR HOUSES, BERLIN, GERMANY.

New filters are being built at Harburg by Dr. G. Thiem, which are quite different in design from those at Hamburg. In January, 1908, these filters were not yet filled, and could be visited to great advantage. This plant has a capacity of 2 640 000 gal. daily, and occupies an area of about 432 by 100 ft., exclusive of the sludge basin, which is about 83 ft. long by 13 ft. wide. The plant consists of a wooden-slat aerator, graded gravel filter, and filtered-water basin. The main distribution channel of the aerator is of iron, but all other parts are wood. The distributing channel discharges into simple wooden gutters with perforated bottoms and notched sides, placed at right angles to the main channel. Beneath the gutters are four superimposed groups of wooden slats. Each slat is 3.2 in. wide and 0.32 in. thick, and is made of fir-wood. The slats, set on edge, are fastened together in grate-like bundles with distance pieces between. Each bundle is 3.2 in. thick, and the spaces between the slats are about 0.32 in. wide. The bundles are in four groups of four bundles each, and there is 8 in. between each group of bundles. The slats in any bundle are at right angles to those in the bundles immediately above and below. The aerator is in four units, and the rate of application is about 16.7 cu. ft. per square foot per hour, or 325 000 000 gal. per acre per diem. Each aerator is surrounded with louvers inclining inward, which admit air to the aerator and prevent the water from splashing outside. The aerators are covered with a brick building, as is the common practice in Germany, contamination of the water by dust being thus avoided. (Plate III.)

The water drops from one bundle of slats to another and finally into a small concrete basin from which it flows to the filter. There is a maximum of 6 ft. of water above the gravel in the filter. The two rectangular filters are built of concrete. By one long side of each filter runs a main collecting drain, which has a semicircular invert of about 14 in. radius, vertical sides, and is nearly 3 ft. deep. The whole bottom of the filter is covered with special hollow tiles cemented in place, giving it a corrugated appearance. Along each side of the main drain runs a wooden strip, about 3 in. wide and 0.5 in. thick, on which rests the oak blocks which form the cover of the drain. These blocks are 4 in. square on end and 4.3 ft. long. Resting on the bottom is a graded layer of coarse gravel, 20 in. thick including the tile, and above this is a layer of fine gravel 45 in. thick. The gravel is of six sizes as given in Table 14.

TABLE 14.

Layer.	Diameter of particles, in millimeters.	Thickness, in inches.
1	50	
2	25	
3	12–14	20
4	10–12	
5	8–10	
6	8–14	45

The difference in level between the water in the distributing channel and that in the filtered-water basin is about 17 ft. When the filter is to be cleaned, the water above the gravel is made to rise about 2 ft. higher than when filtering; a large flap-gate connected with the underdrains is opened suddenly, and the rush of water through the filter flushes the iron hydrate into the sludge basin. The sludge soon settles and is shoveled out.

Director von Feilitzsch, of Brunswick, has used this sludge to purify illuminating gas in place of the ferric oxide produced by rusting metallic iron.* The results have been satisfactory, and, furthermore, a waste product has been utilized.

The filter at Leipsic was built of layers of graded gravel of the thicknesses and sizes given in Table 15:

TABLE 15.

Thickness.		Diameter of particles, in millimeters.
Millimeters.	Inches.	
50	2.	50
325	13.	12 to 14
325	13.	10 " 12
325	13.	8 " 10
325	13.	6 " 8
60	2.4	8 " 10
60	2.4	10 " 12
60	2.4	12 " 14
60	2.4	25
60	2.4	50

The plant at Worms is similar in arrangement to that at Kiel.† It consists of three aerators, two filled with coke and one filled with stone, three filters, and a clear-water basin. There are also small subsiding

*Schillings Journal für Gasbeleuchtung und Wasserversorgung, 49, 714 (1906).
†Gesundheits-Ingenieur, 31, 364 (1906).

basins beneath the aerators. The aerators have a total surface area of 591 sq. ft. It has been proved by experiment that 1 sq. ft. of aerator surface can treat 4.56 gal. of water per minute in a satisfactory manner. This means that 348 sq. ft. of aerator surface would treat the 1 628 gal. of water per minute (2 342 000 gal. per diem) supplied to the aerator. Two aerator compartments are sufficient for this quantity of water, one being held in reserve. This rate is equivalent to 37.4 cu. ft. per square foot per hour, more than twice as great as the customary rate in Germany. The three filters have a total area of 0.118 acre. A rate of filtration of nearly 10 000 000 gal. per acre per diem can be used. One of the three filters is held in reserve.

The interesting plant which is to be built at Posen has already been mentioned, and it is believed that what has been written describes the main types of European deferrization plants.

It is, of course, difficult to compare the efficiency of these types, on account of the varying conditions under which they operate. For example, almost any filter would operate successfully with water like that at Hanover, while there are waters which no existing German plant would adequately purify. The system of Oesten usually fails when the amount of iron is large. It is generally admitted that oxygen is a necessity for the treatment of water, whether it be present by accident or design. Other things being equal, the devices which afford the longest period of contact of the water with the filtering material are the most successful.

Quite recently, Schlegel and Merkel have experimented with the various processes and their feasibility for use with the ground-water in the vicinity of Nüremburg, and have published the following results.*

"1. The process of A. Bock (Hanover), which is patterned after the von der Linde and Hess system, maintained its efficiency without change, but removed only from 43 to 61 per cent. of the iron; the amounts of iron in the filtrate range from 0.16 to 0.62 part of iron per million, and are not parallel with the amounts present in the unfiltered water. The bacteria are markedly increased and the filter material has to be sterilized frequently.

"2. The 'Agga-Verbund' filter (artificial sand-stone filter) removed the iron in a satisfactory manner and without any marked increase in the number of bacteria, but its capacity was diminished to half the initial capacity after three days of use, so that it had to be cleaned frequently, thereby making the cost of operation prohibitive.

*Chemiker-Zeitung, 31, 396.

"3. The deferrization plant at the Truant School in Brunnesburg, where the water falls upon a cascade-like aerator from which it flows upon a simple sand filter with 1-mm. grains, effects a most satisfactory removal of the iron without any bacteriological complications."

Schlegel and Merkel also showed that aeration was not necessary, because the water contained 0.39 part of oxygen per million, and the iron could be removed by simple filtration through sand. In some localities they found that the iron was dissolved in the water in the colloidal form, being kept in solution by organic matter.

"In this case the ferrous hydrate is retained in the sand filter by adhesion or absorption, and afterwards becomes oxidized by the oxygen dissolved in the water. The precipitated ferric hydrate helps the precipitation of the colloidal iron by its coagulating action on the one hand, and, on the other hand, by diminishing the sizes of the pores of the filter, thereby preventing the passage of the fine precipitate."

M. Henri Schwers has made extensive experiments with the water at Turnhout, Belgium.* This water contains organic matter in combination with iron, as well as iron in the form of hydrate. The iron cannot be completely removed by aeration and filtration. He used many different coagulants to assist the precipitation of the iron. Among these were chlorinated lime, sulphate of alumina, ferric chloride, and a mixture of chlorinated lime and ferric chloride known as "ferro-chlor" (Duyk). He used these chemicals singly and in combination, adding them to the aerated water in all cases, and came to the following conclusions:

1.—Chlorinated lime alone is of no especial value as a coagulant in practice.

2.—Sulphate of alumina alone is only of small value as a coagulant in this case.

3.—Ferric chloride is a very efficient coagulant.

4.—The use of chlorinated lime with sulphate of alumina does not increase the efficiency of the latter. The mixture known as "ferro-chlor," has shown no superiority over sulphate of alumina or the ferric chloride used during the experiments.

5.—None of these agents is capable of producing immediate precipitation. Even the ferric chloride with chlorinated lime does not produce precipitation until after twenty-four hours, and this only when conditions are most favorable.

*Révue d'Hygiène, 30, 297 (1908).

6.—The most effective agent for the removal of iron from this kind of water is the deposit of ferric hydrate which accumulates in the filter. The function of organisms in the removal of iron is only a secondary one.

7.—The plan to follow at Turnhout is to depend upon the coating of ferric hydrate on the filter aided by coagulants, especially ferric chloride.

In this connection it is interesting to note that about one-tenth as much coagulant was required with well aged filters as with those freshly filled with clean sand.

The pressure filters of Germany are not to be recommended, either for efficiency or design; in these respects they are far inferior to the rapid filters of American design; but the coarse filter used in so many works is a most valuable device. In it the iron is retained throughout the whole depth of the bed until flushed out. This flushing is accomplished at small expense whenever necessary, and, although the construction cost of these filters is rather high, the cost of filtering the water is very low.

The writer cannot see the necessity for the great losses of head—more than 20 ft. in many cases—which occur in most German works. It would seem possible to get the same amount of aeration and surface contact without necessitating so much extra pumping.

Generally the European filters operate in a very efficient manner; when they fail, it is usually because of lack of oxygen, time for coagulation, or the presence of humus matter. German engineers have attacked the problems presented in a thorough manner, and have worked out practical solutions for all ferruginous waters with the exception of those containing interfering amounts of humus matter.

Experience at Reading, Massachusetts, and Other American Water-Works.

Experience at Reading, Mass.—The quality of the Reading water, the nature of its source, and the different methods of treatment which have been proposed for it, have already been mentioned. As has been stated, the chief obstacle was the presence of organic matter. Evidently interfering amounts of organic matter were not present in 1893, when Mr. Desmond FitzGerald studied the problem on behalf of the town, although he remarks that "the Reading water is no ordinary

fluid." In this report Mr. FitzGerald makes no mention of organic matter, and recommends aeration and subsidence in a reservoir holding two or three days' supply followed by filtration as a method of treatment which will make the water perfectly satisfactory. Two years later, however, the Massachusetts State Board of Health published results of experiments and also its advice to the Town of Reading.* It stated that:

"In one case at least, when the iron was only 0.14 parts per 100 000, aeration in this way (that recommended by Mr. FitzGerald) had but little effect on the iron. The failure to remove the iron in this case seemed to be connected with a considerable amount of organic matter in the water, which prevented the precipitation of the iron after oxidation."

At this time the State Board of Health was not in a position to recommend any method of deferrization; it advised rapid filtration as a temporary measure, and connection with the Metropolitan Water Supply in the future.

It should be noted in this connection that Mr. FitzGerald's belief in the feasibility of purifying the water was established while the meadows were artificially flooded by a dam. Subsequently the dam was removed, and it may be true that the alternate draining and flooding of the river-bottom soil promoted the solution of organic matter and iron from it. It is certainly true that the worst water in the memory of Mr. F. F. Strout, who has had charge of the pumping-station since the works were put in operation, occurred during the winter of 1907-08. This water contained a large amount of iron.

The Massachusetts State Board of Health† made extensive experiments at Reading, and advised the addition of metallic iron by contact with the water, followed by filtration through sand at a rate of 6 000 000 gal. per acre per diem. This method was carefully tested by the Reading Water Commission, but conditions were found when even this method proved inadequate. Iron was then added electrolytically, and while this process greatly increased the mass of precipitate and helped coagulation in this way, there were short periods when it failed, as has been already mentioned.

It was observed sometimes that long periods of subsidence effected little or no change in the character of the water, and, at times, the

*Report, Mass. State Board of Health, 1895, pp. 41 to 43.
†Report, Mass. State Board of Health, 1899.

iron could not be retained even by fine sand filters operating at rates of less than 6 000 000 gal. per acre per diem, especially if the water was aerated.

It would seem as if all the different investigations of the problem had been carried to logical conclusions, but that changes in the character of the water had revealed the growing importance of the organic matter in each case. Therefore, methods which proved adequate during one period of investigation were found to be impracticable on subsequent trial. Lime precipitates the objectionable organic compound* and helps to precipitate the iron. It was used for ten years to treat the water, sulphate of alumina being used with it. However, lime increased the hardness, and it was desirable to devise a method of purification which would obviate its use. It occurred to the writer that if colloidal suspended clay having a negative electric charge could be precipitated by colloidal hydrate of alumina having a positive charge, as is the case in all water-purification plants for the removal of suspended matter from muddy river waters, then colloidal ferric hydrate, which has the same charge as the alumina, would be precipitated by clay. It also seemed reasonable to ask that if the water of muddy rivers which often suffer large additions of highly colored swamp water is almost invariably low in dissolved color, why would not suspended clay absorb the color, that is, the organic matter in the Reading water interfering with the removal of iron? The writer remembered in this connection that the Mississippi River water below its junction with the highly colored Yazoo River was practically free from color when its suspended matter was removed by passage through a Pasteur filter, that is, it contained little or no dissolved color.† Accordingly, on April 19th, 1906, clay was substituted for lime at Reading, and ever since (with the exception of a short period during 1908) the plant has operated without lime.

Lime increased the hardness of the water about 200%, that is, from about 27 to about 81 parts per million, while no increase was noticed in the case of the water treated with clay and sulphate of alumina. It required about 150 lb. of lime daily to treat about 200 000 gal. of water. At the present writing, less than 15 lb. of clay are being used

*Report, Mass. State Board of Health, 1899.

†Mr. H. W. Clark notes that at the Hanley, England, sewage-disposal plant, the mine wastes containing iron and the pottery wastes containing clay, by mutual coagulation, assisted materially in the precipitation of the sewage. *Journal*, Assoc. Eng. Soc., 1908.

for the same amount of water; furthermore, the amount of sulphate of alumina has been reduced from more than 3 gr. to about 1 gr. per gallon. The filters in use with the lime and sulphate of alumina were "Warren" filters filled with sand having an effective size of 0.90 mm. The floc formed with the clay is finer-grained than that formed with the lime, and is not so easily retained by this coarse sand. The speed of coagulation is slower. However, the treated water passing through a fine sand filter was always satisfactory in every respect. Money has been appropriated for the remodeling of the plant, and modern mechanical filters with finer sand, preceded by either a roughing filter or a subsiding basin of increased size, will probably be built shortly, unless an iron-free supply can be found.

Roughing Filters vs. Subsiding Basins.—Experiments were conducted at Reading during 1908 to determine the relative efficiencies of subsiding basins and roughing filters of the same construction cost. After being treated with clay and sulphate of alumina the water was passed through a subsiding basin having a capacity equivalent to about 1 hour's flow, and then into a barrel filled with No. 2 broken stone. Experiment No. 1 extended from March 16th to April 22d. The rate of filtration was 50 000 000 gal. per acre per day, and daily analyses showed the amounts of iron in the raw water, the effluent of the coagulating basin, and the roughing filter, respectively, given in Table 16.

TABLE 16.—Amounts of Iron, in Parts per Million.

Sample.	Experiment No. 1.	Experiment No. 2.
Raw water	2.40	2.28
Coagulating basin effluent	3.24	5.00
Roughing filter effluent	1.70	2.08

The filter was then shut down until May 25th, on account of lack of time to supervise it; after which date it was operated until June 8th, when it was washed. The results are given in the final column of Table 16.

During the last three days of this experiment the amount of iron in the effluent of the roughing filter was greater than in the influent, showing that the suspended matter was being dislodged from the stones and carried away with the effluent. After washing, the efficiency of

the device was restored. The results are a little misleading because the engineer of the pumping-station, Mr. F. F. Strout, who made the determinations, could make but one or two determinations of samples from each source daily, and apparently samples of the coagulating-basin effluent were taken at a time when they contained an abnormal amount of suspended iron. It is apparent, from observations made at the plant by the writer, that little sedimentation of iron takes place in the coagulating basin, although probably it is not true, notwithstanding the results, that there is no increase in the amount of iron after the passage of the water through the basin. The experiments are still going on, but the results cannot be stated definitely at this time. So far they show that more than 29% of the iron present in the raw water and more than 47% of that present in the coagulating-basin effluent is removed by the roughing filter, while its removal by the coagulating basin is a negligible quantity. What is fully as important as the actual amount of iron removed, is the condition of that remaining in suspension after it passes through the roughing filter. This is so well coagulated that passage through ordinary filter paper reduces the amount of iron to less than 0.1 part per million. The period of contact between the water and the filtered material of the roughing filter is about 15 min. A coagulating basin of the same construction cost would provide about 1 hour's storage, which the evidence at hand indicates would prove to be less efficient than the 15-min. storage in a roughing filter of the same construction cost in contact with its filtering material.

It should be noted that this roughing filter was filled with uniform broken stone, and would not be as efficient as one of graded gravel, like those described in another part of this paper.

One advantage of a roughing filter at Reading would be the reduction in the amount of chemical treatment necessary, with clay and sulphate of alumina. It is believed that for a greater part of the year roughing filters followed by rapid filters would remove the iron in a satisfactory manner without chemical treatment.

Deferrization Plants in America.—Few deferrization plants have been built on this continent. Waters containing iron are too often avoided. The plant at Asbury Park was the first one of importance; this was in use in 1894. Since then plants have been built at Far Rockaway, N. Y., Red Bank, N. J., West Superior, Wis., Richmond,

Mo., Reading, Mass., Keyport, N. J., Garrettsville, Ohio, and a few other places. These plants are of three general types, namely:

1.—Aerators and pressure filters.
2.—Aerators and gravity filters.
3.—Gravity mechanical filters using coagulants.

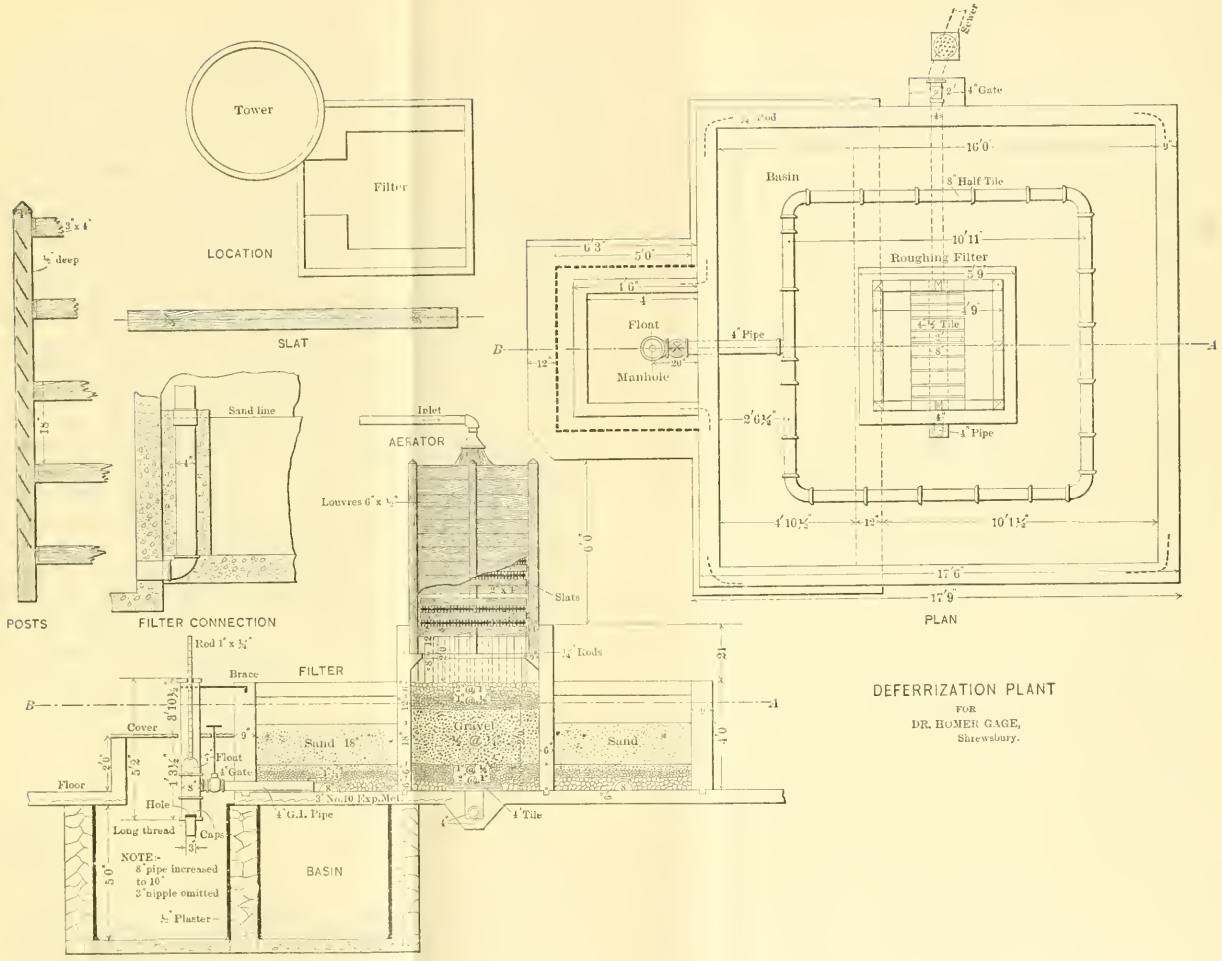
The plants at Far Rockaway and West Superior, designed by Mr. Allen Hazen, resemble the Oesten system more than any other.* The water is aerated by spraying and is then filtered through rather fine sand. The filters designed by Oesten contained coarser filtering material. The plant at Richmond, Mo., designed by Wynkoop Kiersted, M. Am. Soc. C. E., resembles the West Superior plant in principle.†

William S. Johnson, M. Am. Soc. C. E., has recently designed a temporary arrangement for Dover, N. H.‡ Ferruginous spring water is aerated and purified by spraying intermittently upon the sandy soil in the vicinity of wells, from which latter the supply for the city is pumped. While a portion of the water is lost, 95% of the iron is removed, and without great construction cost. This temporary plant will be replaced shortly by a permanent filter.

Recently the writer designed a small deferrization plant for an estate in Shrewsbury, Mass. The water is from an Artesian well in shale. It is very soft, is quite free from organic matter, and contains 18 parts of carbon dioxide, 3.2 parts of iron, and 0.1 part of manganese per million, besides a trace of hydrogen sulphide. Plate IV shows the arrangements of parts, namely, wooden-slat aerator, roughing filter, final filter, and filtered-water reservoir. The capacity is 50 000 gal. per diem.

As the water is soft and contains manganese, it is treated best by thorough aeration and contact with gravel, followed by filtration through sand. Organic matter does not interfere, but the small amount of residue on evaporation (78 parts per million) and the presence of manganese are indicative of a water which precipitates its troublesome elements quite slowly. The filters are arranged to be drained daily so that oxygen may be condensed on the surfaces of the filtered material while out of service. The gravel filter is cleaned by flushing, the sand filter by scraping. The results have been satisfactory.

*"Filtration of Public Water Supplies," p. 186.
†*Richmond Conservator*, Nov. 24th, 1904.
‡*Municipal Journal and Engineer*, 24, 520 (1908).



DEFERRIZATION PLANT
FOR
DR. HOMER GAGE,
Shrewsbury.

Demanganization.

Demanganization of water follows the same general laws as deferrization, but the speed of reaction is slower, one reason for which is that the mass of manganese usually present in ground-water is less than that of iron.*

At the Müggelsee works at Berlin, Director Anklam showed the writer how the red iron hydrate had been retained by the sand of the filter, while the precipitation of the manganese was delayed until the water had passed into the gravel of the under-drain, which gravel was coated with dark brown manganese hydrate. At Stargard (Pomerania), the water after passage through brick aerators was filtered upward through filters composed of 8 in. of coarse gravel, 11 in. of fine gravel, and again 8 in. of coarse gravel, arranged in superimposed layers. The water contains 2 parts of iron per million and small amounts of manganese. The iron is precipitated in the lower part of the filter, but Director Ehlert demonstrated that none of the dark brown manganese hydrate could be seen until the upper half of the fine gravel was reached. The cross-section of the filter showed: first, a red zone of iron hydrate; then one of clean gravel; then a brown, almost black, 4-in. zone of manganese hydrate; then another one of clean gravel. At Brunswick, Director von Feilitzsch showed the writer samples of sediment from different parts of the aerator and filter, which proved that in this case also the iron was precipitated earliest. At Hanover the writer was presented with three samples of precipitate as follows:

No. 298, from the distribution system before filters were introduced;
No. 299, from the filter material;
No. 300, from the water-tower.

These samples were analyzed, the results being shown in Table 18.

TABLE 18.

Number	298	299	300
Iron (Fe)	57.89%	34.72%	14.27%
Manganese (Mn)	0.30%	1.24%	7.15%
Ratio (Mn : Fe)	1:193	1:28	1:3

Sample No. 298 was taken from the pipes at a point where nearly pure iron oxide precipitated. The Hanover filters effect only a partial

*Metallic hydrates precipitate from concentrated solutions faster than from dilute.

deferrization of the water, so that there is an after-precipitation in the water-tower. This after-precipitation is more indicative of the presence of manganese. Sample No. 298 is brownish red, No. 299, reddish brown, and No. 300, very dark brown, almost black, in color. The raw water contains 0.5 part of iron (Fe) per million and traces of manganese.

At Arad, Hungary,* Mr. Rudolph Hajek observed that water from the deep wells before and after deferrization was perfectly clear; also that there was no deposit in the pure-water reservoir at the deferrization plant after a year's use, but in the force main, from the pumping station to the distribution system, where the velocity of the water was only 0.85 ft. per sec., there were numerous brown flocs of manganese hydrate on the upper surface of the pipe and also a deposit upon the bottom. There was little deposit in the service pipes, but the galvanized-iron strainers of the water meters were found to have their holes almost completely choked with a yellowish-brown mass, although the strainers made of copper or brass were clogged but little. A pressure filter placed in the force main near the pumping station remedied the difficulty. The water contains only 25 parts of iron per million and traces of manganese. It has a hardness of 140 parts per million. Another interesting fact was noticed, namely, that the trouble due to manganese is greatest after periods of heavy rain.

Manganese has rarely given serious trouble in America. The first case known to the writer was, in 1898, when a well-water supply for a New England mill contained so much manganese that the well had to be abandoned. This case was mentioned by Mr. Hazen in a private communication, and is the earliest record of troublesome amounts of manganese in a water supply with which the writer is acquainted. In this case, the well was beneath a peaty layer overlying the water-bearing sand.

Manganese occurs in the waters of Reading, Mass., in some of the waters of Long Island, and in many other American water supplies, but usually in small amounts, often accompanied by *Crenothrix ananganifera*.†

The Breslau Calamity.—In former years Breslau was supplied with filtered Oder River water. The Oder River becomes quite turbid at

Schillings Journal für Gasbeleuchtung und Wasserversorgung, Aug. 17th, 1907; *The Engineering Record*, 56, 517.

†D. D. Jackson, *loc. cit.*

times, and the slow sand filters in use frequently passed a turbid effluent of questionable quality. The rapid increase of population in the industrial villages above the city caused a movement for the improvement of this supply. This movement was headed by the distinguished Professor Fluegge, of the Department of Hygiene, of the University of Breslau, who, as is well known, is partial to ground-water supplies. This agitation led to a preliminary study, begun by Baurat A. Thiem in 1892, which resulted, before the close of 1904, in a ground-water supply from the Oder Valley above the city. This supply had a capacity of 16 000 000 gal. daily. It was collected by means of three hundred and thirteen 6-in. wells driven to depths varying from 33 to 40 ft. and placed 70 ft. apart. The wells are arranged in three lines and are overflowed at extreme high water.

The soil of the Oder Valley is made up of a layer of humus matter, silt, and clay, under which is a stratum of alluvial sand of various-sized grains. Beneath the sand is the diluvial clay 100 to 235 ft. thick, the top of which is from 30 to 55 ft. below the surface. The layer of loam, peat, and clay, is from 7 to 10 ft. thick. The ground-water level before beginning the daily pumping is from 20 to 40 in. below the surface of the ground. Beginning with January, 1905, ground-water exclusively was supplied to Breslau. By March 27th, 1906, the ground-water level had sunk to 25 ft. below the surface during pumping; previous to this date there had been little rain.

The deferrization plant consisted of a coke aerator and gravel filter, the plant resembling the Piefke system in design. The aerator is 2 m., the gravel filter 1 m. deep, and there is a small basin between aerator and filter.

On March 28th, 1906, the river rose and overflowed the third line of wells, and later, part of the second line. Soon the soil air caught beneath the flood water appeared in the wells, so much of it in fact that the air-pump could hardly keep the main free. At the same time the amount of iron increased to 440 and the manganese to 220 parts per million. For a time the deferrization plant removed the iron successfully, but the manganese passed on to the city and made the water useless for domestic purposes. As a result, the ground-water supply was abandoned; filtered Oder River water was again supplied to the city, and three open filters were built to tide over the emergency.

Many explanations were at once offered, but even to-day no one explanation is universally accepted. One said that the manganese came from below the water-bearing strata, being forced upward by the pressure of the artesian water through from 100 to 235 ft. of clay and schist. Others, and among them, the geologists, engineers, and a majority of the chemists, believe that Luedecke has proved that the manganese was leached out of the humus-clay stratum by the overflowing river water. This position is hotly contested by the hygienists of the Breslau school, who affirm that the passage of flood water into the wells through the overlying clay stratum is a practical impossibility. Director Debussmann, of the Water-Works, made a thorough experimental study of this question, and states that the river water can reach the wells in as short a time as twelve hours when the valley is overflowed.

American engineers who have used clay in dams and embankments will not place much faith in the impenetrability of from 7 to 10 ft. of river-bottom soil; and, although it may be true that some of the dissolved manganese diffuses from the upper stratum, it seems to be proved that river water did pass through it directly. At Reading the soil is not unlike that of the Oder River Valley, and the writer has repeatedly seen pools of rain water disappear into the ground during six hours of pumping.

Luedecke states that the Oder Valley soil contains much iron and manganese in the form of sulphides.* As long as these sulphides were not exposed to the air they remained unchanged. The lowering of the ground-water level brought air in contact with these insoluble sulphides, which then oxidized to sulphates and free sulphuric acid, which latter is an active solvent of iron and manganese. The acid could act as a solvent, because the soil is not rich in lime and other alkalies which would neutralize the acid. This process went on for a year and a half, when a sudden flood caused the appearance of the accumulated iron and manganese in the ground-water. Of course it is presumable that diffusion had something to do with this appearance, but this seems to be an inadequate explanation, because after a subsequent flood in September, 1906, the amount of iron in the water of the overflowed wells rose suddenly to more than 100 parts per million, and the water became acid to litmus. A measurement of the rise in ground-water

*"Gesundheit," 1907.

level showed that about 1 325 000 000 gal. of water had seeped into the water-bearing layer during this flood. This explanation agrees with the writer's experience at Reading, where the highest amounts of iron and manganese followed a flood or a sudden heavy shower preceded by a long period of comparatively dry weather. As before stated, there is more manganese in the Arad, Hungary, water supply immediately following a rain.

Several methods for removing the manganese from the Breslau water have been proposed. H. Luerig and A. Blasky* have advised the treatment of water after deferrization, first with lime, followed by aeration, sedimentation, and filtration, and finally with carbon dioxide gas—practically a softening process. Many of the wells, however, are unaffected by floods. They are in use at the present time, and, if the writer is informed correctly, new wells are to be sunk to take the place of those which, during floods, contain too much manganese to be removed by the present deferrization plant. In this way the ground-water supply is to be gradually restored, and the filtered river-water supply abandoned; the filters now being used for river water will ultimately be used for ground-water, as at Berlin.

Since writing the above there has appeared a paper by Professor Beyschaly, Director of the Prussian Geological Survey, and Dr. R. Michael, which gives an account of studies made to learn the cause of the trouble at Breslau.† They, also, believe that the calamity was due to the manganese leached from the top soil of the valley and not to the water from beneath the lower clay layer, which water contains little iron, only traces of manganese, and differs from the more superficial waters in nearly every way.

Design of Deferrization Plants.

The design of deferrization plants is governed largely by the character of the water. The subject is best discussed under the following heads, which are the names of the various parts of such a plant: Aerators; Subsiding basins; Roughing or contact filters; Final filters; Apparatus for chemical treatment.

Aerators.—If it is desirable to remove carbon dioxide from the water, the more thorough the aeration the better, and for this purpose

Chemiker-Zeitung, 31, 255.

†*Schillings Journal für Gasbeleuchtung und Wasserversorgung*, 51, 84.

one may use a great variety of devices. The tower type of aerator, such as is used in Germany, has the advantage of aiding the precipitation of the iron by contact with rough surfaces, which effect is not obtained in aerators consisting of simple sprays or superimposed perforated pans.

Where the water contains organic matter in colloidal solution and it is a disadvantage to liberate the carbon dioxide, it is often better to supply the requisite amount of oxygen by simple spraying or by admitting air into the suction of the pumps. The disadvantage of the tower type of aerator is that a head of from 3 to 10 ft. is lost, and it seems to the writer that, if contact action is desired, it would be more economical to aerate by a simple spray, or superimposed perforated pans, or admission of air into the suction, and then pass the water through coarse gravel, thereby providing both aeration and contact without undue loss of head.

Subsiding Basins.—Where the precipitation is rapid, well-baffled subsiding basins effect a decided economy, because they relieve the final filter of much work. In such cases they are to be preferred to a roughing filter of the same construction cost.

Roughing or Contact Filters.—These filters are simply beds of gravel through which the water passes, either intermittently or continuously, and either downward or upward. Experiments at Reading, as before noted, show how efficient these roughing filters are in preparing that water for final filtration. In most cases they are more economical than subsiding basins, and in many cases remove practically all the iron from the water. They should be designed, like some German filters, to deposit the iron all through the filtering layer, and not on the surface only. The gravel should have rounded grains so that the bed may be flushed with ease.

The rate of filtration through roughing filters cannot be prescribed without knowledge of the water to be treated. For many waters a rate of 50 000 000 gal. per acre per day may be used. When higher rates are used, the retention of iron hydrate may be diminished. This factor also is dependent on the character of the water.

Final Filters.—Final filters may be of varying degrees of fineness, ranging from the gravel which will be retained by a sieve having four meshes to the inch to sand having an effective size of 0.12 mm.

It is desirable, when coarse material is used, to cause the precipitation of the iron throughout the whole layer of filtering material instead

of near the surface, as is best in the case of surface-water purification. In Germany this is accomplished by grading the filter material. Filters of this kind, at Leipsic, Stargard, and Harburg, have been already described.

The aim of all deferrization plants is, of course, to increase the speed of precipitation, and it may be laid down as a general rule that the coarser final filters are most useful in waters which precipitate their iron rapidly and in coarse flocs. Waters which are difficult to treat, however, while they may be improved greatly by passing through a coarse roughing filter of ordinary thickness, almost invariably require a final filtration before being suitable for consumption. Mechanical filters are almost invariably used with waters requiring chemical treatment. There are no materials superior to sand and gravel for use in filters.

The properly treated water may be filtered through the final filters at almost any practicable rate, and for this purpose mechanical filters are to be preferred, as a rule. However, slow filters at 15 000 000-gal. rates may be found more economical in many cases, especially where preceded by roughing filters, which latter would increase the quantity of water filtered between scrapings. At Far Rockaway, N. Y., a growth of algæ forms a mat on the surface of the bed, which mat can be easily rolled and removed, taking with it the accumulations of iron at the surface of the bed, and reducing the cost of scraping.

Apparatus for Chemical Treatment.—The apparatus for applying sulphate of alumina should be the same as that used for the purification of muddy river waters. Lime can be added either in the form of milk of lime, or, more economically, as a saturated solution, as is practiced at St. Louis, Mo., and other cities. Clay is best added in the form of a suspension. The clay for this purpose should be selected carefully, and that which has the largest percentage of finely-divided particles should be chosen for use. It should be mixed with water, the heavier particles should be allowed to subside, and the suspension of fine particles should be fed into the water by an orifice tank through which the suspension is circulating continuously. A thorough mixing of the chemicals with the water to be treated hastens the speed of precipitation. Very often it is desirable to subject waters treated with chemicals to a preliminary filtration through a roughing filter before giving them a final filtration. The decision in this case

should depend on the comparative costs of coagulating basins and roughing filters of like efficiencies, and the costs of scraping or washing the final filter with and without such preliminary treatment.

The writer feels disinclined to discuss the arrangement and choice of ozone apparatus, with the limited data at hand. It is enough to say that the ozone treatment is simply aeration with ozonized air, and the ozonization of the water takes place under similar conditions, but with the exclusion of the external air.

Conclusion.

The first requisite for the deferrization or demanganization of a water is a thorough knowledge of the water itself, not only from a chemical, but also from a physical and geological standpoint. All alkaline ground-waters will precipitate their iron ultimately, although it may require months in some cases. Those moderately hard waters free from any considerable amount of organic matter, which begin to throw down iron as soon as they appear above the surface of the ground, need only to be aerated and filtered through coarse material; while those which precipitate iron more slowly require more aeration and more contact with filtering material and the accumulated ferric hydrate to get good results.

Those waters containing interfering amounts of organic matter must be specially treated. Either there is an excess of organic matter holding the iron hydrate in suspension, an excess of iron holding the organic matter in suspension, or the organic matter is in colloidal solution and interferes with the precipitation of the ferric hydrate.

In the first two cases it is necessary, in the language of physical chemists, to "balance" the electric charges of the suspended particles. That is, if the iron be in excess, add a negative colloid like suspended clay or organic matter; or if organic matter be in excess, add iron or aluminum hydrate. If organic matter in solution interferes, it is possible to add lime, which forms an insoluble compound with the humus matter; to treat the water with ozone which destroys it, or to increase the bulk of precipitate by adding both positive and negative colloids, for example, sulphate of alumina and clay, and, by the absorptive action of the greater bulk of precipitate, to overcome its effect.

In a few words, the aim of every process should be to allow time

enough for the oxidation and coagulation of the iron or to shorten the required time by aeration, by contact, by balancing the several kinds of suspended colloidal matter so as to precipitate one another mutually, or, if necessary, by increasing the mass of precipitate so as to outweigh the effect of all interfering substances which may be present in the water treated.

The writer wishes to acknowledge the assistance and advice of many engineers and chemists, most of whom have been mentioned. He is especially indebted to the Reading Water Board and its officers for the opportunity to test various arrangements of apparatus on a large scale.

DISCUSSION.

Mr. Lounsbury.

WILLIAM C. LOUNSBURY, ESQ.* (by letter).—Mr. Weston mentions the difficulties which may be encountered in removing iron from underground supplies. The plant at Superior, Wis., has certainly had its share of troubles arising from this difficulty, and a brief account of the somewhat peculiar conditions and experiences may prove of interest, in the light of Mr. Weston's suggestions.

Superior is the second city in Wisconsin, and is located at the head of the Great Lakes. A narrow strip of sand, some 7 miles long and a few hundred feet wide, runs parallel to the Wisconsin shore, about a mile from the city and mainland. Lake Superior washes the outer shore of this sandy stretch, and Superior Bay, the inner shore. This land, called Minnesota Point, is principally made up of a fairly coarse sand, mixed with considerable quantities of fine particles of metallic iron. In the formation of the point, logs, peaty matter, clay, and débris have undoubtedly been incorporated with the sand, so that the clean sand of the surface shows no indication of what may be underneath.

About ten years ago, the Water Company decided to draw its supply from wells to be located on Minnesota Point, along the shore of the lake. By this means, it was thought, an excellent supply of filtered water could be obtained. Accordingly, eighty odd wells were jetted to a depth of about 14 ft. These wells were 6-in. wrought-iron pipes, carrying Cook brass strainers, and were spaced about 17 ft. apart, each being separated from the main suction by a valve. The tops of the wells were below high-water level, and the ingress of the water was some 25 ft. below this. The shore line varies, but the wells are approximately 20 ft. from the lake and 400 ft. from the bay across the point. During high water, the water washes over the wells, but, on account of the ice in winter, and in times of low water, the free water of the lake may be several hundred feet away. The water derived from these wells was extremely disappointing. It was harder than the lake water, although not as hard as the bay water; moreover, it carried considerable iron.

In 1901, G. C. Whipple, M. Am. Soc. C. E., made an analysis of the water, as follows:

Total solids	78
Nitrogen as:	Total.
Albuminoid ammonia	0.066
Free ammonia	0.016
Nitrites	0.001
Nitrates	0.04

* * * * * *

* Chemist and Superintendent of the Water-Works, Superior, Wis.

Mr. Lounsbury.

	Total.
Iron	1.50
Hardness	48.5
Alkalinity	46

The character of the water has remained practically unchanged since. The water as described was used under direct pressure to the city for several years, but caused much trouble. The iron settled out in the pipes; *Crenothrix* appeared in great quantities; and all the characteristic objections to iron manifested themselves in a marked degree. The water was particularly disagreeable because it became highly colored, after being drawn from the wells, and this highly-colored water was confounded, by the public, with the objectionable, highly-colored water of the bay, under which the intake passes. This latter water, it may be stated, carries considerable organic matter, leached from tamarack swamps, and also iron in solution. Its color varies above 100.

In 1899, Allen Hazen, M. Am. Soc. C. E., designed and constructed an iron removal plant, for the local company. This plant* consists, essentially, of an aerating device, by which the water showers through holes in iron trays, and falls as spray into a well beneath. The trays are enclosed in a skeleton house, the sides of which are shutters, arranged so as to give free access of the air to the water. From here, the water flows to covered sand filters, and is filtered at a rate of about 5 000 000 gal. per acre, per day. This method of treatment at once gave improved conditions, and the effluent has never since supported any growth in the mains, or deposited iron in them to any extent. Strangely enough, however, the water showed, by analysis, an iron content of 0.7, or 0.8, or even 1.0 part of iron in the filtered water, and an average color of 30, varying from a minimum of 25, to a maximum of 40. To reduce the iron still further, the aerator was heightened, so that more air came in contact with the water. This gave no beneficial results.

The carbon dioxide content is fairly constant, at 1.2 parts. Aeration as used reduces this to an amount of from 0.4 to 0.6 parts.

The writer's experience with the plant commenced in May, 1906. It was very important, at that time, to remove the color of the effluent, on account of local political conditions. In studying the matter, and in the light of a few bottle experiments, the plant was run for several days without the use of the aerator. The result was an immediate reduction of color and the iron content in the effluent. The iron was almost completely precipitated, and the color was reduced so much that the water was perfectly satisfactory. The results are indicated on the diagram, Fig. 9, which shows the decided change that takes place when the aerator is put into use, or is by-passed.

* Described at length in *Engineering News*, February 21st, 1901, p. 141.

Mr. Lounsbury.

In Fig. 9, the time of putting the aerator into operation is marked with a cross, *X*, and the time of by-passing is marked with a double cross, *XX*.

The samples of water were collected at the pumps, so that the effect is seen several hours after the time marked. Samples were analyzed at least once in 4 hours, during the entire period shown. The slight increase of color on October 16th is due to placing in operation a filter previously filled with aerated water.

The analyses were all made by the writer, and are expressed according to the American Public Health Association standards.

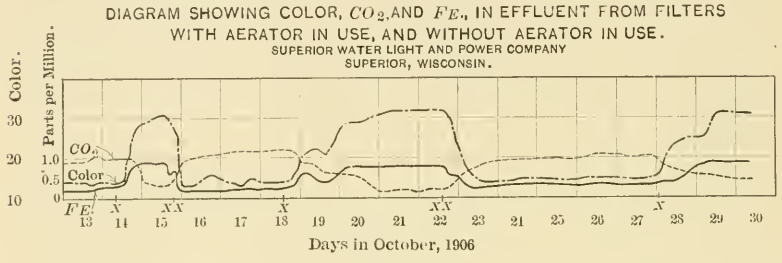


Fig. 9.

The most obvious thing done by this treatment, or lack of treatment, was to allow the filtration to take place in the presence of a greater amount of carbon dioxide, and to pass the water to the filters without violent shaking. There is always an excess of air in the water, through leakage of the system and at the pumps, therefore the writer is inclined to think that the amount of oxygen present does not play an important part. This condition was exactly what had been found in the laboratory. Bottles of the same raw water had been taken. Into one was run carbon dioxide, charging the water under the atmospheric conditions prevailing. The other bottle was simply stoppered. Both were well shaken, and allowed to stand. It was found that the one containing the excess of carbon dioxide always precipitated its iron readily, without attaining the yellow color the control bottle did. Other bottles, after having stood a year or more, have invariably deposited most of the iron, although not always losing their color. The quantities of precipitant deposited on the filters when operating without aeration, was so great that the filters were totally inadequate to handle it. Ordinarily, with aeration, a filter runs from 7 to 9 days; without aeration, one dies in 3 or 4 days.

Non-aeration has been tried, at different times, for more than two years, and has invariably produced a satisfactory effluent, having a color of from 15 to 18 and an iron content of never more than 0.5 part, and frequently as low as 0.3. These experiments have covered ranges of water temperature from 34 to 60°, and air temperature of

from —30° to +90°, the rates of filtration varying with the varying consumption of the city, and the loss of head due to the age of the filters. A proportion of lake water has also been admitted, the alkalinity of which was 40, and the hardness 37, and containing no iron; but always with the same result. Mr. Lounsbury.

Mr. Weston reports a manganese content of 0.12 part in this water, and possibly this plays an important part in the trouble. Whatever the explanation may be, it is certain that the Superior water has been so constant in composition for the past few years that the iron can be readily and easily precipitated, and the color can be kept from forming, by filtering without aeration. Possibly Mr. Weston can explain just why this is so.

Arthur L. Terry, Jr., Jun. Am. Soc. C. E. (by letter).—It may be of interest to those undertaking the purification of ground-water to know that a deferrization plant of 700 000 gal. daily capacity was installed for the Government by Hungerford & Terry at Fort Hancock, Sandy Hook, N. J., more than a year ago. Mr. Terry.

The original water supply of the fort consisted of a series of well points driven into the sand about 6 ft. below the surface. These gave a very good water until the consumption reached about 75 000 gal. a day, when evidences of sea-water began to be found, and increased to such an extent that four years ago two deep wells were installed, one 450 ft. and the other 750 ft. deep. The water from both these wells was very soft and good in every way, except for the iron content, which reached about six parts per million in both wells. The deeper well flowed at an elevation of 15 ft. above tidal water, discharging about 20 gal. per min. The water contained considerable quantities of hydrogen sulphide. Like most deep-well waters, it was clear when first discharged, but in a short time developed considerable turbidity. An attempt to use this water without treatment resulted in so much dissatisfaction that the authorities reverted to the old supply. After a year, two settling reservoirs were built and air-lifts were installed, the idea being that aerating the water would oxidize the iron; and that the settling reservoirs, which gave about 5 days' sedimentation, would permit all the iron to be removed. This plant was completed about 2½ years ago, and put into operation, but it was found that while the oxidation of the iron appeared to be very rapid, and that this precipitated iron settled with considerable rapidity, yet about 30% of the iron remained in solution. At about that time a proposition was made by Hungerford & Terry to install a plant using lime as a coagulant, utilizing the settling reservoirs and supplementing the plant with mechanical filters. This proposition was accepted, and the plant was installed substantially as follows:

The two wells, each of which would discharge 250 gal. per min. when using the air-lift, were conducted into an orifice box containing

Mr. Terry. two adjustable orifices. The large orifice is set so that the head of water varies from 1 to 2 ft. over the orifices, depending on the discharge of the wells. The area of the large orifice is about 17 sq. in., that of the small orifice is about $\frac{1}{4}$ sq. in., and both are placed at the same elevation, so that the discharge of one is approximately proportional to that of the other, regardless of the fluctuations in head. The small orifice discharges into a lime saturator. This saturator consists of a conical vessel, at the bottom of which is placed about a bushel of freshly slaked lime. The incoming water from the small orifice is discharged at the bottom of the saturator, and, to aid in a thorough mixing of the applied water with the lime, a small air line is run from the air compressor, which produces a constant ebullition part way up the saturator. A conical hood, terminating in a pipe reaching above the water level, carries the air to the surface after it has performed its duty of mixing the lime and water. All below this hood is a violently agitated milk of lime, while above and outside the hood there is a solution of lime gradually clearing as the surface is reached. The outlet of the saturator is on the side at the top, and when raw water enters the saturator it displaces an equivalent amount of a clear saturated solution of lime, and in its turn is converted to milk of lime. The quantity of water applied to the saturator is ordinarily about 7 gal. per min., and this, of course, displaces a corresponding quantity of lime water. This lime water is applied to the raw water from the large orifice as it enters No. 1 reservoir. Coagulation is almost instantaneous, and is complete.

The water takes about two days to pass through the two settling basins, and, although apparently clear, a very considerable amount of iron is still left. This fact has been determined, not by analysis, but by observing the wash-water from the filters, the latter requiring washing twice a week.

The filters are mechanical filters of the pressure type, each having a capacity of 360 000 gal. per day of 24 hours, or 720 000 gal. per day for the two units.

The lime required for this plant costs only 80 cents per million gallons, and does not seem to vary with the seasons, for the lime feed has not been changed since the plant was first installed. That the correct quantity of lime was being used was determined by testing the alkalinity of the water with phenolphthalein. When the filtered water shows a faint pink color with phenolphthalein, the removal of the iron is almost complete, although a pink reaction in the water before filtration also indicates very satisfactory results. It is a rather remarkable fact that the water reacts strongly to phenolphthalein before filtration, and yet shows no reaction afterward.

The following report of the water comes from the office of the Surgeon-General of the United States Army:

"The first [sample] is the water as it comes from the wells. It is a turbid water of a very faintly alkaline reaction, odorless, of a yellowish color, due to the marked amount of suspended ferruginous matter. This settles on standing to an appreciable deposit, leaving it a clear, colorless supernatant fluid. Mr. Terry.

"The second is the water after treatment through the filtration apparatus. It is absolutely clear and colorless, is faintly alkaline in reaction, contains an almost inappreciable sediment on standing for many hours, and is without odor. There is no visible charring or carbonization in the residue on its incineration. There thus appears a great improvement in the water by the removal of what small amount of organic matter it contained, together with practically all of the iron, and at the same time the amount of the mineral matter was reduced in its total by one part per million. The actual amount of iron present in this sample is 0.0140 part per hundred thousand, while its hardness (Clark's) is 4.54 per hundred thousand.

"EDWIN R. HODGE,
"Chemist in charge."

Unfortunately, the Government did not report the analysis of the raw water as it came from the wells, but another analysis, made at the same time, showed the total iron to be six parts per million.

Before the receipt of the analysis of this sample, the contractors requested that another sample be taken by the Government for analysis, they believing that a still higher efficiency could be shown by increasing the lime to such a point that the filtered water would react slightly with phenolphthalein. This was forwarded to the War Department, and the following analysis was returned:

"Contained iron 0.0088 part per hundred thousand.

"Total solids: Treated water, 49.50. Raw water, 82.50 parts per million.

"EDWIN R. HODGE,
"Chemist in charge."

Experience with this plant indicates that the lime treatment, when installed as described, is cheaper than any other process, not excepting aeration. To be sure, an air-lift is used in conjunction with this plant, but that is only for 6 hours per day, and, during the remaining time, the well flows and there is no aeration of the incoming water, the result being obtained by the lime alone.

When it is considered that this plant has no skilled supervision, but is run by employees whose sole duty (with regard to the plant) is to wash the filters twice a week, and slake and discharge into the saturator a few bushels of lime; and, also, that the plant always maintains an almost total reduction of the iron content, this method of deferrization is worthy of notice. Those who have tried to introduce clay or milk of lime into water with any degree of accuracy know what a difficult and unsatisfactory proceeding that is.

Mr. Terry. Taking the experience at Reading, reports state that the water was hardened very considerably. On the other hand, the Fort Hancock plant showed virtually no change in the hardness, except on the occasion of the second analysis, when the lime was increased to a point at which softening began; but then, instead of increasing the total content of the water, there was a reduction of nearly 50% in the total solids.

Referring to aerating towers of coke or other substances, it seems, from the knowledge at hand, that elevating the water and cleaning such towers, to say nothing of the interest on the investment, would make the cost greater than treatment by lime, and there can be no doubt that a lime-treated water will contain far less iron than one which relies merely on aeration.

To carry the matter further, it even seems that some of the abnormal conditions which have arisen at Posen and other places might be handled successfully by the lime process, followed by subsequent filtration. A slight excess of lime applied to a water containing a large amount of humus is a most energetic coagulant, and it certainly should be far more effective than the present methods.

The only objection that the writer can see to the use of lime is in the uncertain methods by which it has been applied in the past. An excess of lime, under ordinary conditions, is an unpleasant feature, but when applied in the manner described, an excess is an impossibility if the plant is designed properly. The worst that could occur would be a deficiency due to inattention of the operative in not placing slaked lime in the saturator.

Mr. Burgess. PHILIP BURGESS, ASSOC. M. AM. SOC. C. E. (by letter).—This excellent paper will doubtless prove of great interest to all engineers engaged in the installation and operation of public water supplies. The information contained tends to make clear many of the problems encountered in the search for an economical water supply of satisfactory quality. The question of approval of ground-waters has been frequently referred to the Ohio State Board of Health, and the writer has made many examinations of water from ground sources, waters which have contained frequently such large quantities of iron as to be unsatisfactory for domestic use without purification.

In the Middle West it is frequently necessary for the engineer to judge between the advantages of a supply from ground sources and one of purified surface-water. While the former is frequently clear and potable, it is sometimes so objectionably hard that a surface-water would be more desirable. The double cost of pumping, generally necessary with ground-water supplies, sometimes makes the cost of operation less than that of a filtered surface-water only to the extent of the cost for a coagulant necessary when the water is purified with mechanical filters. The costs of construction shown by Mr. Weston in Fig. 1 are

evidently based on slow sand filters. The average cost of thirteen mechanical filter plants of varying capacities in Ohio, including low-service pumps, coagulation and sedimentation basins, filters, and clear wells, is about $14 000 per million gallons, while the cost of operating the purification devices averages about $6 per million gallons. These figures show that the cost of securing a filtered water supply of surface origin is frequently not much greater than that necessary to procure a satisfactory ground-water. Moreover, the latter is frequently so hard that the total expense to the consumer is considerably greater than is the case with the softer surface-water. Cases are not infrequent where a ground-water supply has become dangerously polluted without the knowledge of the operator until a considerable quantity of badly polluted water has been pumped to the consumers. In the writer's opinion, such conditions are very rare with a well-constructed and operated filter plant. Mr. Burgess.

One feature relative to the distribution of iron-bearing waters is little touched upon by Mr. Weston, and that is the great variation in the quantity of iron in water from different strata in the same locality. The writer has in mind, especially, two wells at Newton Falls, Ohio, one 58 ft. deep containing 3.0 parts of iron per million, and the other, not 50 ft. distant, 35 ft. deep, and containing 20.0 parts of iron per million. Similar variations have been found at different depths in other parts of Ohio.

Mr. Weston's discussion on the design of iron-removal plants is so general that it will hardly serve as a reference for engineers who have to study the problem of the purification of a specific ground-water. The scarcity of the data on such plants in America and the great variations in the character of the water to be treated, doubtless account for the absence of more specific statements. The following data are presented in order to show what has actually been accomplished by iron-removal plants at Garrettsville and at Shelby, Ohio.

The water supply for Garrettsville is derived from ten driven wells varying in depth from 41 to 70 ft.; also from a shallow dug well or flowing spring. The wells and spring are in a ravine just above the confluence of two small streams. The wells pierce, first, a layer of yellow clay of varying depth, and second, a layer of white sandstone rock, from 40 to 60 ft. in depth and of nearly pure silicious material. The lower 8 ft. of the sandstone strata are of a conglomerate nature and comprise the water-bearing material from which all the wells derive their supply. The water is of generally satisfactory quality for domestic use, except that its iron content is about 2.0 parts per million. It was for the removal of iron that a purification plant was constructed in 1906. The devices provided for the removal of iron comprise an aerator, a sedimentation basin, and a mechanical filter.

The aerator consists of an umbrella-shaped device on the discharge

Mr. Burgess.

of a low-service force main. It is 4 ft. in diameter and approximately 5 ft. above the level of the water in the basin. When the plant is in operation, water from the wells is lifted by the low-service pump, and, at the point of discharge into the basin, falls back on this umbrella-shaped device which breaks it up into a fine spray. The sedimentation basin is divided into four compartments, about 12 ft. square and 9 ft. deep. Its total capacity is 39 000 gal. The filter is of the gravity mechanical type, and is a rectangular concrete tank with a total area of 96 sq. ft. The filtering material comprises 12 in. of graded gravel and 36 in. of sand of about 0.3 mm. effective size.

During a recent inspection by the writer, the consumption at Garrettsville was about 25 000 gal. daily and the rate of pumping on low service about 2 000 gal. per hour. This gives a period of sedimentation of practically 20 hours and a rate of filtration of approximately 21 000 000 gal. per acre per day. The settling basin is cleaned about once every 3 months, and it is found that practically all the sludge accumulates in the first compartment, where there is generally a deposit about 1.5 in. in depth. Every 3 days it is necessary to back-flush the filter, which is accomplished by applying filtered water from the reservoir. Washing is accomplished in about 10 min., and requires about 15 000 gal. of water, equivalent to about 20% of the total quantity filtered.

The consumers appear to be very well satisfied with the quality of the water, and the plant is operated without difficulty, but at considerable excess cost due to the unusually large quantity of wash-water necessary. This could be reduced by improving the washing system of the filter.

The water supply for Shelby, Ohio, is obtained from ten 6-in. driven wells in the alluvial plain bordering Black Fork Creek. The wells vary in depth from 40 to 60 ft., and are from 200 to 300 ft. from the creek. They pierce the following material, in the order stated: Loam, clay, hardpan, gravel, slate, sandstone rock, and water-bearing gravel. The thickness of the strata is not known, but it is said that the slate and sandstone are both thin. The fact that leaves and twigs were found in some of the wells at considerable depths indicates that, in prehistoric times, the ground from which the water is obtained was of a swampy character.

During pumping, water generally stands in the wells about 19 ft. below the surface of the ground, and it was not lowered during the recent exceptionally dry spell. This would indicate that the water is derived from ground sources, and not from the creek. Although objectionably hard, the water is of generally satisfactory quality for domestic use, except that its iron content is 6.6 parts per million.

The water was used without purification for eight years, but considerable trouble was caused by the precipitation of the iron in the

mains, and a purification plant was built in 1905. This plant com- Mr. Burgess.
prises an aerating tank and two horizontal pressure filters. The aerating tank is of steel, 120 ft. high, and 8 ft. in diameter, and is placed concentrically within the old stand-pipe, which is 130 ft. high and 16 ft. in diameter. In the top of the tank are provided steel plates perforated with 1-in. holes 2 in. apart. The plates are 2 ft. apart, staggered, and each covers one-half the cross-section of the tank, so that the actual distance between the plates is 4 ft.

The filters are horizontal steel tanks, 24 ft. long and 8 ft. in diameter. In the bottom is a collecting system, above which is placed 18 in. of screened gravel and 18 in. of crushed quartz sand. The latter will all pass through a screen of 16 meshes per inch and be retained on a screen of 30 meshes per inch. Its effective size is approximately 0.75 mm.

The present daily consumption at Shelby varies from 250 000 to 300 000 gal. Water from the filters is pumped directly into the mains, and the plant is operated 24 hours. The force main from the low-service pump is carried up inside the outer compartment of the stand-pipe and discharges into the aerating tank, in which the water is generally maintained at least 10 ft. below the top. The aerated water flows by gravity through the filters, and is pumped into the mains. The average period of sedimentation in the tanks is about 4 hours, and the filters are operated at about 30 000 000 gal. per acre per day. They are washed once a week, using from 20 000 to 40 000 gal. of water. The initial and maximum losses of head are 2 and 6 lb., respectively. The stand-pipe is flushed out about once a month, but little sediment is removed.

On January 14th, 1909, the writer, in company with Mr. C. F. Long, of the Laboratory Department, made an examination of the Shelby plant. During this examination it was the purpose, as far as possible, to make the necessary analyses in the field. The temperature, turbidity, color, dissolved oxygen, alkalinity, iron, oxygen consumed, and total bacterial content were determined at the plant, while the other analyses shown in Table 19 were determined on samples shipped to the laboratory of the State Board of Health. The examination covered 18 hours' operation of the plant, but indicated little variation in the character of the water at the several sampling points.

The analyses of the raw water indicate that it was clear, hard, of high iron content, and contained no dissolved oxygen; its free CO_2, free ammonia, and oxygen consumed were all high, while nitrates were absent. The water was practically sterile.

The analyses of the aerated water indicate a considerable change by aeration, notably the increase in turbidity due to the oxidized iron; the elimination of considerable free CO_2 displaced by dissolved oxygen; and a reduction in alkalinity. The total iron content was not reduced,

Mr. Burgess.

TABLE 19.—Results of Analyses of Samples Collected at Shelby, Ohio, on January 14th, 1909.

(Parts per Million.)

Determinations.	Raw water.	Aerated water.	Filtered Water.	
			At filter.	In mains.
Temperature, in degrees, centigrade	10.9	10.1	9.9	11.5
Turbidity	0+	60±	10±	5+
Color*	3	.....	45	25
Free CO_2	48	28	24.5	22
Dissolved oxygen				
(Parts per million)	0	7.8	7.7	7.5
Percentage saturated	0	69	68	69
Alkalinity	263	248	241	240
Incrustants	214	220	215	220
Total hardness	477	468	455	460
Total solids	713	.....	713	.....
Loss on ignition	73	.....	82	.....
Total iron (Fe)	6.5	6.7	0.85	0.60
Magnesium	31	.....	31	.....
Chlorine	11.8	12.5	12.5	13.5
Oxygen consumed	3.65	2.58	2.13	1.90
Nitrogen as				
Free NH_3	5.80	.....	0.180	.....
Alb. NH_3	0.112	.....	0.104	.....
Nitrites	0.002	.....	0.002	.....
Nitrates	0	.....	0	.....
Bacteria per cubic centimeter	1	.....	1	.....

* On unfiltered samples.

but the latter was in a changed form, and was chiefly in suspension as an oxide.

The analyses of the filtered water indicate that the filters removed most of the suspended iron, so that the final product contained but 0.85 part per million. The color determinations indicate that the residual iron was in suspension. The samples from the mains indicate a further reduction, or iron sufficient to cause an accumulation of deposits in the mains and a slight staining of plumbing fixtures.

In the writer's opinion, the efficiency of the filters could be considerably improved were the filtering material replaced by a greater depth of finer-grained sand having an effective size of about 0.3 mm. In general it may be said, however, that the purification devices have served to eliminate the objectionable features, so that consumers are now generally satisfied with the quality of the water.

An interesting point brought out by the analyses is the considerable reduction of alkalinity by the aeration of the water and the oxidation of the iron, a fact which tends to show that the latter is present in the form of a carbonate. There is also a striking reduction of free ammonia, which apparently goes off as a gas, as the filtered water contains no nitrates. Further information on these points is very desirable.

A. Elliott Kimberly, Esq.* (by letter).—While there are many factors which favor the use of water supplies from ground-water sources, it is to be remembered that ground-waters in the Middle West are usually hard and, from this standpoint, objectionable. Methods of water filtration for the removal of suspended matters and bacteria have reached such a state of efficiency that, ordinarily, it is feasible and economical to consider thoroughly the use of a surface-supply, rather than derive the supply from ground-water sources. This is particularly true where the surface-water is soft and the ground-water hard. The small increase in operating charges incidental to the operation of a filter plant is but slightly more than the actual money loss incurred by the consumer of the hard ground-water. The argument is still more forcible where deferrization is necessary, and, before deciding on the use of a hard, ferruginous ground-water, all reasonable means should be investigated for obtaining a softer supply from surface sources. Mr. Kimberly.

The presence of iron in ground-waters often prevents their use as sources of water supply, unless means be provided for removing the iron, and to this important subject Mr. Weston has certainly contributed a mass of valuable data.

The writer was at one time engaged in studying the water at Reading, Mass., under the direction of Mr. H. W. Clark, where the difficulty encountered in removing the iron was attributed, not so much to the presence of organic matter, as to the fact that the iron was present in the form of a sulphate, or, more correctly, was accompanied by the sulphate radical, SO_4, rather than by the carbonate radical, CO_3. To this fact was ascribed the greater ease of iron removal by aeration possible in the cases of the Provincetown and the Watertown waters.

It is interesting to note that it is not the nature of the acid radical, but the presence of organic matter, as Mr. Weston's researches clearly show, which prevents the precipitation of the iron after it has been oxidized.

As is well known, the removal of clayey matters in suspension is readily accomplished in water-filtration practice by sulphate of alumina. The use of a clay-bearing, ferruginous water as a precipitant for domestic sewage, as at Hanley, England, suggests several interesting Ohio experiences.

The sewage of Sebring, Ohio, in volume about 46 000 gal. in 24 hours, flows in an open ditch into Sulphur Creek, which has its rise in an abandoned coal mine. In dry weather, the creek flow is at the rate of about 28 000 gal. in 24 hours. The crude sewage is essentially domestic, is ordinarily weak, and contains a predominance of sink wastes and soapy matters. The Sulphur Creek water is an acid mine

* Asst. Engr., Ohio State Board of Health.

Mr. Kimberly.

waste which contains free mineral acid, very large quantities of iron, high sulphates, and other constitutents peculiar to mine drainage. Analyses of the Sebring sewage and of the Sulphur Creek water are given in Table 20.

TABLE 20.—Analyses of Sebring Sewage and Sulphur Creek Above and at Several Points Below Their Confluence, Illustrating the Precipitation of Iron-Bearing Waters by Colloidal Matter.

Sampling points.	Parts per Million.							Bacteria per Cubic Centimeter.
	Turbidity.	Alkalinity.	Nitrogen as Free Ammonia.	Chlorine.	Dissolved Oxygen.	Iron (Fe).	SO_4	
Sulphur Creek.....	0+	—62*	0.8	23	0	50	1 044†	135
Sebring sewage.....	500	350	16.0	94	0	....	....	600 000
150 ft. below confluence.	250	154	13.0	59	0	40	808	8 000
1 mile below confluence.	5±	24	3.0	38	0	2	495	5 300

* Free sulphuric acid present. † Incrustants.

About 150 ft. below the confluence of the two streams, marked coagulation is visible. The velocity of the current is very slight, and, for a mile or more from the point of confluence, the stream is practically a sedimentation basin under continuous operation. At its outlet, one mile below the confluence, the supernatant water shows practically no turbidity and, besides being substantially free from iron and free acid, contains but little evidence of the marked organic pollution it has received.

The bottom of the stream, however, is a mass of putrefying sludge with a slight surface coating of ferric hydrate, surmounting a mass of black, nauseating, and foul deposit. These conditions are illustrated in Table 20. They indicate the effect of semi-colloidal sewage upon the iron present in mine wastes, and are another example of the deferrization of ground-waters by means of colloids.

Several further illustrations of the use of negatively-charged clay particles in hastening coagulation occur to the writer. At Warren, Ohio,* the Mahoning River water is purified by mechanical filters of the wooden tub type, and, at times, the turbidity of the raw water is so slight that clay is used to start the coagulation. At Newark, Ohio,* during certain seasons, the raw water is derived chiefly from the ground, and is so free from turbidity that it cannot be coagulated with sulphate of alumina unless clay be used. Clay has also been used at

* See forthcoming report of Ohio State Board of Health on Water and Sewage Purification Plants.

Harrisburg, Pa.,* and Ithaca, N. Y.,† to assist in obtaining a satis- Mr. Kimberly.
factory floc under certain conditions of the raw water.

The question of iron removal is of special significance and importance in connection with problems of water supply for small villages. Recognizing the allowable limit of 0.5 part per million of iron in a potable water, what means are available and should be recommended for removing iron from ground-waters when present in objectionable quantities?

In reviewing the foreign and domestic deferrization plants, as described by Mr. Weston, it is apparent that there are several distinct types:

Aerators, sedimentation tanks and open filters (mechanical or slow sand);

Aerators and pressure filters;

Air-lift pumps, head tank, pressure filters, clear well or direct connections to mains.

Available evidence as to the best practice in the design of deferrization plants appears to be somewhat fragmentary, and it is apparent from Mr. Weston's paper that the design depends primarily on the character of the raw water, which should be carefully investigated. It is obvious that aerating devices and pressure filters which, in the absence of organic matter, are successful in removing the iron with sufficient thoroughness, show somewhat high operating costs, owing to the heavy loss of head necessary and the large volume of wash-water required. It would appear from Mr. Weston's theoretical discussion that, at times, aeration alone will not suffice to effect the precipitation of the oxidized iron, owing to the colloidal form of the ferric hydrate; nor will aeration, sedimentation, and open sand filters, when organic matter is present. It appears, therefore, that the only plan always feasible (except for water similar to that at Reading, Mass.) is a combination of aerators and pressure filters, or aerators, roughing filters, and pressure filters. In other words, the precipitation of the iron is effected ordinarily by a combination of chemical oxidation and mechanical separation induced by the adsorptive effect of the ferric hydrate previously precipitated upon the filtering medium. On this account roughing filters appear favorable as a means for lightening the load on the finishing filters, and doubtless would take the place of an aerating tower, particularly if the water be raised by an air-lift. In such cases pressure or open mechanical filters are to be considered, and not slow sand filters.

Alexander Potter, Assoc. M. Am. Soc. C. E. (by letter).—The Mr. Potter.
author has made an exhaustive and valuable research. The presence

* Harrisburg, Report of Board of Commissioners of the Water and Lighting Department, 1907, p. 24.

† "Operating Results of the Water Purification Plant at Ithaca, New York," *The Engineering Record*, Vol. 57, 1908, p. 673.

Mr. Potter. of iron and manganese in ground-waters is well established. The purification of such waters is an important subject, and has been treated fully in this paper. Although the author states that the paper "does not concern itself with methods of water-softening or alkali reduction, but with the theory and practice of the iron-removal processes in use in Europe and America," still there are so many waters containing iron and manganese, where these constituents form the simplest and least refractory ones to be treated, that the discussion might well include processes which will soften the water and remove, as well, other impurities far more serious than iron and manganese.

Along the Southern Atlantic and also along the Gulf Coast, well-waters containing iron are for the most part also hard. This is also true of many other well-waters throughout the country. In Western Pennsylvania, both surface and well-waters contain iron. Some of the sources of this iron are mine drainage, washings from coke ovens, and refuse from mills. Certain of these waters contain more iron than many of the supplies specifically mentioned by the author. For instance, the supply at McKeesport, Pa., has at times as much as 25 parts per million of iron, whereas the supply at Worms contains 9.5; Reading, Mass. (November, 1891, highest), 13.3; Berlin, 1.2; New Orleans, 3.2; Provincetown, Mass., 3.6.

There is no doubt whatever that for certain classes of water, including those which are naturally soft, the method described and advocated by the author will prove the cheapest and best; but a comparison of the figures derived from the diagram, Fig. 1, showing the cost of the filtration of river waters and the deferrization of ground-waters, with the actual cost of water-softening plants which have come within the writer's observation, would indicate that water-softening processes can be installed oftentimes with very little more expense than for a plant constructed simply for the deferrization of the water; with the added advantage of giving a greater return upon the investment and producing a water which is much more satisfactory for all purposes. Where the water is hard and ferruginous, there is no difficulty about the removal of the iron by aeration or coagulation without attempting softening, and the supply is thus improved, but the relatively small additional cost of providing for the softening of the water warrants the consideration of a complete softening plant, rather than one simply for deferrization.

The water of the Youghiogheny River perhaps contains more iron than that of any other river in that part of the country, and it is present in solution as sulphates; but the amount of iron in the river was not as great as that in the well-water which, until the commencement of the operations of the softening plant, formed a part of the supply for McKeesport. The sulphate hardness, both iron and calcium, was so great at times as to warrant the abandonment of the ground-

water supply altogether, especially as the geological formation in the vicinity of the water-supply station indicated possibilities of pollution from surface sources. Mr. Potter.

The presence of the salts of iron in such waters as the Youghiogheny is of great benefit in the softening process, for when acted upon either by carbonate of soda or hydrate of lime (the two constituents most generally used in water-softening processes), the hydrate of iron is precipitated. Because of its flocculent nature, this and the hydrate of aluminum make the best coagulating agents known. On several occasions during the testing of the McKeesport softening plant, the deficiency of carbonate of soda and hydrate of lime, during the period when the iron and aluminum content in the water was high, gave rise to a colloidal condition of the iron and aluminum hydrates so that they could not be precipitated, no matter how long the period of settlement, and they passed through the mechanical filters unchanged. These iron and aluminum salts have also the well-known action of rendering the calcium carbonate (left in the water as a result of treatment) less soluble.

An added reason why water-softening should receive more general consideration in the discussion of ground-water supplies, is the value of the settling tanks in the removal of bacteria. Analyses at McKeesport show that the settling tank is performing the bulk of the work. A test made on January 25th, 1909, gave 13 000 bacteria per cu. cm. in the raw water, and in the filtered water 50 per cu. cm. Of the total amount, 99% was removed in the settling tank. On January 29th, 1909, a test showed that with a bacterial count of 5 000 per cu. cm. in the raw water, the settling basin effluent contained 90 per cu. cm., while the filtered water was sterile. This gives an efficiency of 98.2% for the settling tank and 100% for the entire plant.

These are representative tests. The plant has been in operation for nearly four months, having been started before its full completion because of the terrible condition of the raw water in October, 1908.

H. F. Dunham, M. Am. Soc. C. E. (by letter).—If not too far from the main subject of this excellent paper, brief mention of the author's experience in the location of supplies of ground-water with reference to nearby surface waters would be appreciated. Mr. Dunham.

At Superior the wells are 400 ft. from the shore of the lake. The lake water, like most surface-waters, contains little iron, yet it is undoubtedly the source of the water supply. What would be the change in the quantity of iron in that supply if the wells were 40 ft., instead of 400 ft., from the shore line? It seems hardly reasonable to think there would be greater difficulty in maintaining wells at that or even at a less distance from the shore. If the iron is taken up as the water percolates through the sand, a less distance might yield less iron.

Mr. Dunham. A marked improvement in the number of parts of iron per million followed the location of a system of wells close to and partially underneath an Illinois stream. In water from sand-bars in a Southern river the iron diminished to one-fourth of the first determined amount under continued pumping from a group of wells during a season when the iron in the river water was steadily increasing. However, it was at all times less than the amount of iron in the sand-bar supply, but the distance of wells from surface-waters and the diminution in quantity of iron under the long-continued operation of a plant are items of interest.

Mr. Kuichling. E. KUICHLING, M. AM. SOC. C. E.—The growing public interest in ground-water supplies, as well as the author's scholarly presentation of the subject, makes the paper both timely and valuable. The economical removal of solutions of iron and other metals from waters found at greater or less depth below the surface of the earth has long been regarded as a purely chemical problem, but it is not generally known that such solutions are sometimes also eliminated in the subsoil itself by the action of various microscopic organisms of vegetable nature. This part of the subject was discussed orally by the author at much greater length than appears in the paper, and was made very interesting by the exhibition of a number of lantern slides. Among these were several views showing accumulations of such organisms on the inner surface of cast-iron water mains, of sufficient thickness to reduce seriously the diameter of the pipes.

The speaker has devoted much time to a study of the nature of the incrustations often found in water pipes, and would therefore inquire whether the accumulations shown in the photographic views consist wholly of the organisms described (*Crenothrix* and *Leptothrix*), or whether the incrustation does not consist largely of fine earthy matter deposited from the water along with rust derived from the pipe itself. In most of the dry specimens which he has seen, the quantity of vegetable tissue was comparatively small, and the filaments seem to have entangled much of the mineral matter carried in suspension by the flowing water. On the other hand, in freshly broken pipes, the lining of living organic matter sometimes appears to be quite thick while kept under water, but shrinks enormously on drying.

The speaker first became acquainted with *Crenothrix* in 1883, in Berlin, where it had developed in the water mains some years previously to such an extent as to cause much trouble. The water was first derived from a series of shallow wells on the shore of a small lake, and when the organisms began to appear in noticeable degree an improvement was sought in vain by taking the water from greater depths by means of many tubular or driven wells. The spores of *Crenothrix,* however, were found at depths of more than 60 m. below the surface, and the final

remedy was sought in filtering the well-water. From the description then received, the individual organisms seemed to attach themselves at favorable points to the inner surface of the large cast-iron force-main, and then to develop into larger colonies, forming brush-like gelatinous masses which became detached whenever the velocity of the water was considerably increased. These masses were generally disintegrated in passing through the long main, and rendered the water unsightly, but occasionally they were large enough to obstruct the service pipes in the city. Mr. Kuichling.

Shortly after returning from his visit to Europe, the speaker investigated a similar condition of the water supply at Jamestown, N. Y., and eventually traced the cause of the trouble to *Crenothrix* derived from both shallow and tubular wells. The well-water seemed to be perfectly clear, but under the microscope it was found to contain a few minute filaments which resembled the organism mentioned, and which probably lodged and developed extensively in the distributing pipes. At the time of the investigation, many of the colonies had evidently been detached and broken up by preliminary flushing operations, so as to give the water drawn from hydrants and large service pipes the appearance of being mixed with saw-dust. In this form of small brownish lumps, it was difficult to recognize *Crenothrix,* and the identification was made only after finding some specimens that exhibited the characteristic structure of the organism, and seeing it in the act of emitting its spores.

Since that time the speaker has found *Crenothrix* in several other water supplies, but not to the same extent as at Jamestown or Berlin. It has also been reported in many other localities in America, so that the name is now familiar to water-works engineers. Although of such frequent occurrence, little has yet been published of its life-history and the methods of eliminating it economically from sources of water supply; and, as the author has evidently studied these matters exhaustively, the speaker would be much gratified if they could be treated more fully in the closure of the discussion.

J. W. Ellms, Esq.* (by letter).—In this exhaustive paper Mr. Weston has called attention to a subject which is of interest to all who are engaged in water-purification work. His admirable classification of the phenomena relating to the properties of iron- and manganese-bearing waters merits special attention, as it is the first attempted correlation of a number of well-known facts which have hitherto escaped a satisfactory grouping. Mr. Ellms.

For a number of years the writer has believed that a more thorough knowledge of the properties of those bodies known as colloids would lead to a better understanding of many of the obscure physical and

* Superintendent, Cincinnati Filtration Plant.

Mr. Ellms. chemical changes which take place in both water and sewage purification. Some years ago, in a published paper* and in an address,† he called attention to certain phenomena characteristic of turbid water produced by clay in suspension. By experiment it was shown that turbid Ohio River water exhibits the Tyndall effect, showing the path of a beam of light in the same distinct manner as do colloidal suspensions of gold and arsenious acid. It was also shown that under the influence of an electric current these clay particles migrated toward the anode, and, therefore, in the same direction as in artificial suspensions of kaolin. These properties of minute clay particles suspended in water, together with the ability of electrolytes to coagulate them, all tended to place clay-bearing waters in the class of colloidal suspensions. These clay particles appear to carry the negative electric charge, and not the positive charge, as do compounds of iron, aluminum, and manganese. If the electrical theory is true, it offers a fairly satisfactory explanation of the mechanism of coagulation of clay particles in turbid waters by the salts of aluminum and iron commonly used in water purification. The positively-charged ions of these salts neutralize the negatively-charged ions of the suspended clay compounds, and, thereby, produce flocculation and precipitation of the colloid. It is not so clear, however, why positively-charged ions of aluminum salts are so much more effective than those of iron in the precipitation of the presumably negatively-charged ions of colored organic compounds which color many natural waters. It is probable, as Mr. Weston points out, that one must distinguish between humus compounds, which exist as true colloids, and those which are present as a colloidal suspension.

The writer believes that many of the earlier explanations upon biological grounds of the phenomena of purification of both water and sewage, are only partly true, and that the real causes of purification may be more properly attributed to physico-chemical changes involving colloidal bodies. The life activity of the organisms in these processes appears to the writer as incidental to, rather than the cause of, clarification and purification. Many of the phenomena characteristic of water-softening processes, and especially those connected with the modern rapid methods of sewage treatment, are undoubtedly associated with colloidal compounds.

A better and clearer conception of the properties of colloids will aid materially in the design and construction of both water and sewage purification plants. Oftentimes failure or success in design depends on seemingly unimportant phenomena, the principles which underlie them being either carelessly overlooked or little understood.

* "The Coagulation and Precipitation of Impurities in Water Purification," by J. W. Ellms, *The Engineering Record*, May 13th, 1905.

† "Colloidal Suspensions and Their Relation to Problems in Water Purification," by J. W. Ellms and J. F. Snell. Read before the American Chemical Society, June 22d, 1905.

Mr. Pearse.

LANGDON PEARSE, ASSOC. M. AM. SOC. C. E. (by letter).—Mr. Weston is to be congratulated on his monograph. His remarks on the European trend toward the development of ground-water supplies are decidedly interesting, as Europe was the pioneer in the filtration of surface supplies. In the United States, because of their cheap first cost, underground supplies have usually been installed, if there has been any choice.

There has been a very marked development of ground-waters in California, both for irrigation and for city supplies. The water is not always soft, in many cases it is very hard, sometimes alkaline, but it is usually clear, sparkling, and cool, qualities which the impounded surface waters often lack, since the warm climate and long periods of storage common in California promote the growth of algæ. Oakland, Cal., is supplied by the Peoples Water Company, which furnishes about 6 000 000 gal. per day from driven wells, in addition to the draft from its impounding reservoirs. The water is hard, having an average total hardness of about 200 parts per million; but it is low in incrustants, sometimes alkaline, with a low iron content of from 0.04 to 0.25 part per million, and a chlorine content ranging from 22 to 145 parts per million, averaging about 63. The surface water impounded in the large reservoir (Lake Chabot) has quite different characteristics, an alkalinity of about 155, a total hardness of 160, a chlorine content of 20, and iron from 0.2 to 2.6, all in parts per million. Most of the wells are located at Alvarado, on the edge of an underground storage fed by the run-off from the Niles Cañon. During 1888 to 1890 there was a very extensive development of underground water near the outlet of this cañon, by the Spring Valley Water Company. This forms part of the supply for San Francisco. The chemical characteristics of this water are probably similar to those of Alvarado, with a somewhat lower chlorine content.

For those who are not familiar with this development, a few quotations are given from the testimony of Mr. H. Schussler, in a brief submitted recently, in the case of Spring Valley Water Company *vs.* the City and County of San Francisco, before the U. S. Circuit Court. This is known as the Alameda Creek System, and consists of some 600 sq. miles of water-shed back of the Town of Sunol.*

"The run-off from Calaveras Creek, Arroyo Valle, and San Antonio Creek, as well as from the Artesian wells at Pleasanton, is all carried practically to an underground dam built on the bed-rock in Sunol Cañon, which has been filled in by Nature with gravel to the extent of about 1 400 acres; in these gravel beds, a long cement tunnel has been built for over 14 000 ft., in order to catch the water coming from this water-shed after it has filtered through this natural filter bed, and

* For a map of this country see Plate LIX, *Transactions*, Am. Soc. C. E., Vol. LXI, accompanying the paper on "Rain and Run-Off near San Francisco," by C. E. Grunsky, M. Am. Soc. C. E.

Mr. Pearse. thereby San Francisco gets an average of over 14 m. g. d., running up to 17 m. g. d. on individual days. * * * The water from the various sources is simply run on to a large natural bed of gravel, from which every pollution whatever is kept, and allowed to sink into the gravel, which is of variable depth. * * * Underlying the gravel is a bed of stiff blue clay, and some stiff blue clay mixed with tight gravel. * * * In order to draw the water off from this subterranean gravel bed, which not only acts as a filter bed, but also as a storage reservoir of all water on the ground from where it cannot escape, because the Spring Valley Water Company owns the outlet of the valley and on it has a bed-rock dam made of concrete, so that all of the water so sunk has got to come either over the dam or through the filter tunnel that Spring Valley has constructed through the bottom of this valley, with several branches partly of timber, and, in the deeper portions, of concrete; this filtered water is drawn from this concrete channel by means of gates and gate-houses."

This development illustrates Mr. Weston's suggestion that artificial ground-water can be made, but it is a development which is suited only to unusual circumstances and very favorable surroundings. It is certainly not a method which can be very generally applied. The Peoples Water Company, the Spring Valley Water Company, and the Los Angeles Water-Works, which has several driven-well stations and a filter gallery driven out under the gravel bed of the San Gabriel River, are probably the largest municipal developments in California. In all these cases, however, the underground supplies are but a portion of the whole, and further increases are being sought in more or less distant surface supplies. Undoubtedly one reason for the lack of development of ground-water supplies, except in a small way, has been the uncertainty of the amount available. Underground storage is not a definite quantity, and cannot be calculated as exactly as the storage of a reservoir.

Recently, the writer's attention was called to an interesting well, near Oakland, Cal., where the water layers found in drilling were of very different character. The ground surface was a fairly tight adobe, extending down some 30 ft. or more, then clay, then gravel and sand. The upper water is rather brackish, while the belt below the clay is full of H_2S, presumably leached out from underground deposits of iron pyrites which are known to exist some two miles above the well.

The writer has frequently noticed that iron-bearing waters occur in pockets, so to speak, and that a water nearby may have a moderate or low iron content. The differences in the chemical quality of wells which are comparatively close to one another is illustrated clearly by the case at Brooklyn, N. Y.*

While the average supply from the Ridgewood Reservoir had an alkalinity of 16.7 and a total hardness of 35.7, with an iron content

*Report of Commission on Additional Water Supply for the City of New York, pp. 424 *et seq.*

of 0.4, all in parts per million, this being a mixture of surface and well waters, the individual analyses from certain wells were as follows: Mr. Pearse.

Hardness, in Parts per Million.			Iron.
Alkalinity.	Permanent Hardness.	Total Hardness.	
1.4	7.0	8.4	0.27
115	8.6	123.6	0.70
80.6	159.4	240.0	2.02

All the independent water companies operating in Brooklyn have had hard supplies, with a total hardness ranging from 93 to 183 parts per million. Undoubtedly some of the differences are due to the strata from which the well draws, and the depth; data on this were not obtained.

The question of the pollution of ground-water supplies is an interesting one on which there is little information. In a thickly populated section, where the ground-water is near the surface, the pollution factor may be large, particularly where privies with unlined pits are used. In such cases the danger would have to be studied in view of the storage and resulting death of the disease bacteria. In 1904 some experiments on the spread of pollution were made by the writer, under the direction of George C. Whipple, M. Am. Soc. C. E., for the Commission on Additional Water Supply.*

These experiments seemed to show that in a sandy soil, such as is found on Long Island, the danger is not great, provided the source of pollution is sufficiently removed. The conclusion stated in the Report was that:

"With low velocities, polluted water passing through the finer sands that exist on Long Island for a distance of 25 ft. may be considered as practically safe for use, and it is probable that in most cases a distance less than this would serve as an efficient safeguard."†

There was, however, no doubt that the number of bacteria found in this case was high, though the numbers of bacteria and *B. Coli* were undoubtedly reduced by the liberal use of chloride of lime as a disinfectant. The effect of rain was to increase the number of bacteria, both in the surface and lower layers, measurements being made at depths of 2, 7, and 17 ft.

The effect of acids and alkalis on colloidal suspensions of clay is a very practical question, particularly in filtration work. The writer would like to ask if Mr. Weston has found any data showing that the effect has been reversed by the use of a concentrated instead of a dilute acid or alkali.

* Report of Commission, pp. 567 *et seq.*

† Page 568.

Mr. Weston. ROBERT SPURR WESTON, ASSOC. M. AM. SOC. C. E. (by letter).—The writer thanks the members and others for their contributions in connection with his paper.

Mr. Lounsbury's interesting experience is in line with that at Reading, Mass., and at Turnhout, Belgium. It is quite evident that the presence of carbon dioxide prevents the formation of a compound of iron and organic matter; that excessive aeration removes the carbon dioxide; that iron can be oxidized in the presence of carbon dioxide, as shown by Dunbar,* and that the compound of iron and organic matter often passes through filters imparting to the effluent its relatively high color, which color, according to Schwers, is due to the presence of this compound in colloidal suspension. There is enough oxygen in the unfiltered water to oxidize the iron without further aeration, and the carbon dioxide is present in sufficient amounts to prevent the formation of the highly colored compound of iron and organic matter, while on the other hand it is not concentrated enough to hold the iron in solution by its own solvent action. It is due to Mr. Lounsbury that the part which carbon dioxide plays in such cases as this was brought to the attention of the Profession.

Mr. Terry's description of the deferrization plant at Sandy Hook is very illustrative. This appears to be a case where the complete removal of carbon dioxide greatly accelerates the coagulation and precipitation of the iron. The process is known in Europe as Krohnke's. The device for adding lime water is worthy of commendation, although it does not appear to the writer to be as simple and flexible as the differential weir used by Handy at the Winnipeg, Man., softening plant. The disappearance of the slight pink color in the effluent produced by the addition of phenolphthalein may be due to the reduction of the slight excess of alkali through the well-known favorable influence which the filtering material with its accumulated ferric hydrate exerts on chemical reaction. The action is carried further than is possible in the basin, hence the decrease in caustic alkalinity due to an excess of lime and a more complete precipitation of the iron.

When lime is added to remove the carbon dioxide from a soft water, no increase in hardness can result; but where lime combines with acids to form soluble compounds, for example, sulphates, the hardness is sure to increase. Hard waters which are softened by the addition of lime are of course very different, and the problem becomes one of water softening, with deferrization as a side issue. When hard water is softened the iron is invariably removed at the same time.

It is established beyond a doubt that soluble iron cannot be precipitated from water without aeration. At Sandy Hook this aeration

* Dunbar, *loc. cit.*

is no less real because accidental. The writer feels obliged to disagree with Mr. Terry's general statement that treatment with lime in subsiding basins is cheaper than aeration and filtration. In Europe roughing filters are more efficient than subsiding basins of the same construction cost. The loss of head in the roughing filters need not be more than 2 ft., and is unimportant. The cost of wash-water for cleaning the roughing filters is very low; usually, its volume is less than 1% of the water pumped. At Far Rockaway, N. Y., the aerators and sand filters remove the iron economically without lime, without excessive loss of head, and at a low cost. One practical difficulty which must be met is the objection, on the part of some authorities, to the addition to a supply of any chemicals whatever. Mr. Weston.

Caution should be observed in the use of air-lift pumps. With certain waters the introduction of air into the wells causes the iron to precipitate in the ground, clogging the strainers eventually. At Brunswick, Germany, it is necessary to close the wells as soon as the daily pumping is finished. If even aerated water were allowed access to the well tubes they would soon clog.

The writer omitted purposely certain details of description from his paper, in order to confine himself to the elucidation of the principles of the deferrization processes. Therefore Mr. Burgess' descriptions from practice are the more welcome.

Generally speaking, it would seem that the natural protection afforded to ground-water by the soil is more efficient than that supplied by sand filters, unless, of course, the soil contains fissures and caverns, as may be the case in limestone regions. It is often possible to obtain a ground-water supply soft and free from iron by the use of the softening process. Sometimes this is little, if any, more expensive than a filtered surface water.

The suggestion by Mr. Dunham that the amount of iron in wells like those at Superior, Wis., might be reduced if the wells were driven nearer rivers or lakes is a valuable one and usually works out in practice, but it should be borne in mind that wells driven near polluted bodies of water often show evidences of pollution, especially during flood seasons.

The importance of the theory of colloids in engineering work, as brought out by Mr. Ellms, is just beginning to be realized. Not only does the modern conception enter into water purification and sewage disposal, but into the formation of deposits from natural waters, the water-proofing of concrete, the setting of cement, protective coatings for metals, and many other and rapidly increasing fields.

For the life history of *Crenothrix* the writer would refer Mr. Kuichling to the papers by Mr. Jackson* and Professor Schwers.†

* D. D. Jackson, *Transactions*, Am. Micro. Soc., 23, 32.

† *Révue d'Hygiène*, 30 (1908).

Mr. Weston. In practice, the nature of deposits in pipes depends on several factors, among which are the rate of precipitation of the iron independently of the growth of *Crenothrix,* the food supply and rate of growth of the organism itself, and the formation of the iron sheath of the organism. Sometimes deposits consist almost entirely of the organisms and their iron sheaths. Such was the nature of the deposit shown at the time the paper was read. Again, the deposit may consist largely of ferric hydrate with a few stray organisms embedded in the mass. The organisms themselves, like the sewage fungus, *Leptomitis,* for example, have a very frail structure, and are made up of a large percentage of liquid; so that, when the organism dies and is dried, it occupies but a small part of the space which it did in its living condition. Schwers* showed that deposits of ochre occurred in company with many kinds of organisms, including diatoms and other algæ, that *Crenothrix* is not essential for this deposition, and that usually it plays a relatively unimportant rôle. Whether or not *Crenothrix* can grow in the absence of oxygen is not known. Furthermore, it has never been cultivated in iron-free media. It is possible that it may derive the oxygen necessary for the precipitation of the iron on the sheaths from the nitrates which are contained in all ground-waters. *Crenothrix* generally occurs where the water-bearing stratum is overlaid with a stratum of peaty soil, whence the organic matter which favors their growth is derived.

Mr. Pearse has called needed attention to the varying iron content of ground-waters. Even waters from two adjacent wells often differ in the amount of iron contained therein. In reply to Mr. Pearse's question regarding the effect of different concentrations of acids and alkalis upon colloidal suspensions of clay, the writer would refer him to an article by Messrs. Whitney and Straw,† in which they state that colloidal suspensions are made much more stable by the addition of a trace of alkali; also, that dilute alkaline solutions of definite concentrations have certain peculiar effects. The increase in the concentration of the OH ions up to a certain point increases the stability of the colloidal suspension, while still further increase decreases the stability because of the excess of OH ions.

It has been the writer's experience that the slightly alkaline clays are the most readily kept in suspension, while the clays which are mixed with suspended silt are most readily precipitated. Clay of this kind is often observed in the water of the Kentucky River, and when it occurs the water is difficult to coagulate.

If the writer's memory and information are correct, acids *per se* do not increase the stability of colloidal suspensions of clay. When added to a suspension containing a slight excess of alkali, however,

* *Loc. cit.*

† *Journal*, Am. Chem. Soc., 29, 325.

they may reduce the concentration of the alkali, form an electrolyte, and cause the precipitation of the suspended matter. Acids added in excess to suspensions of metallic hydrates would prevent precipitation because of their solvent action. Mr. Weston.

One way, of course, to prevent stoppage of service pipes and mains is the deferrization of the water. The writer knows of no other method, although it is possible that the sterilization of the water by chlorine, as used for the sterilization of some surface waters, might effect a removal of these organisms. The writer has never had a case where the growth of *Crenothrix* clogged the well tubes, but he has always believed that this growth might be reduced to a minimum by closing the suction of the pump after each pumping, thereby preventing the accession of aerated water to the wells. He also believes that, if practicable, the wells should be driven so deep that the water will be oxygen-free when drawn.

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TRANSACTIONS

Paper No. 1107

STRESSES IN MASONRY DAMS.

By William Cain, M. Am. Soc. C. E.

With Discussion by Messrs. E. G. Walker and William Cain.

The object of this investigation is to determine the amounts and distribution of the stresses in a masonry dam, at points not too near the foundations, having assumed the usual "law of the trapezoid," that vertical unit pressures on horizontal planes vary uniformly from face to face.

Experiment indicates that such vertical stresses increase pretty regularly in going from the inner to the outer face, for reservoir full, until we near the down-stream or outer face, where the stress gradually changes to a decreasing one, which decrease continues to the end of the horizontal section. The law of the trapezoid is thus only approximately true over part of the section, but, as it gives an excess pressure where it attains a maximum, it errs on the safe side.

The profile of the dam selected is of the triangular type, with some additions at the top, but the method used in determining the stresses is general, and will apply to any type of profile. The final equations will give, at any (interior or exterior) point of the horizontal section considered, the vertical unit stress on the horizontal section, the normal stress on a vertical plane, and the unit shear on either horizontal or vertical planes. From these stresses, the maximum and minimum normal stresses, and the planes on which they act, can be determined, and ultimately, if desired, the stress on any assumed plane can be ascertained.

The solution presented is approximate, which is justifiable, in view of the approximation involved in "the law of the trapezoid" used. The results, however, are practically correct, as will be evident from the checks applied, resulting from the exact theory given in the Appendix. The theory used, being simple, should be easily followed.

Let Fig. 1 represent a slice of the dam contained between two vertical parallel planes, 1 ft. apart and perpendicular to the faces. The batter of $O\,B$ is $\frac{130}{200} = \frac{0.65}{1}$; that of $O\,E$ being $\frac{4}{200} = \frac{0.02}{1}$. The batter of the inner face was found by trial, so that the centers of pressure on horizontal sections, for reservoir empty, should nowhere pass more than a fraction of a foot outside the middle third of the section. The simple type of profile shown was adopted for ease of computation.

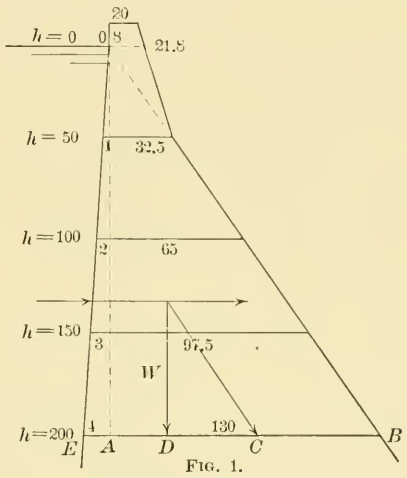

FIG. 1.

For convenience in subsequent computations, the breadths, $b = E\,B$, of horizontal sections, corresponding to various depths, h, below the surface of the water in the reservoir, are given, all dimensions being in feet:

$h = 199.0,\ b = 133.330$
$h = 199.5,\ b = 133.665$
$h = 200.0,\ b = 134.000$
$h = 200.5,\ b = 134.335$
$h = 201.0,\ b = 134.670$

Take the weight of 1 cu. ft. of masonry equal to 1; then the weight of masonry above any section is equal to the corresponding area in

Fig. 1 above that section. The area of the portion above $E\ O\ B$ is readily found to be 712, and its moment about the vertical, $A\ O$, is 11 603, the unit of length being the foot. In Fig. 1, D is where the vertical through the center of gravity of the dam above the joint, $E\ B$, cuts that joint, and C is the center of pressure on that joint when the water pressure on $E\ O$ is combined with the weight of masonry, W, above $E\ B$.

As h varies, suppose each horizontal joint, in turn, marked similarly to the joint at $h = 200$, with the letters E, A, D, C, B; then, for any joint, on taking moments of the triangles, $A\ O\ B$, $A\ O\ E$, and the area above $O\ B$, we find

$$A\ D = \frac{\frac{A\ O}{6}\left(A\ B^2 - E\ A^2\right) + 11\ 603}{W}$$

Assuming that the masonry weighs $2\frac{1}{2}$ times the water per cubic unit, then the weight of a cubic foot of water is $\frac{2}{5}$. It would entail but little extra trouble here, where the inner face has a uniform batter throughout, to include the vertical component of the water pressure on the face, $E\ O$; but it will be neglected, as usual.

The horizontal water pressure for the height, h, is thus, $\frac{2}{5} \times \frac{h^2}{2} = \frac{1}{5}\ h^2$, and its moment about C is $\frac{1}{5}\ h^2 \times \frac{1}{3}\ h = \frac{1}{15}\ h^3$.

Taking moments of W and water pressure about C, we have at once,

$$D\ C = \frac{1}{15} \times \frac{h^3}{W}.$$

From the last two formulas, we derive the following results:

h	W	$A\ D$	$D\ C$
199	13 978.335	40.49141	37.58483
200	14 112.000	40.70316	37.79289
201	14 246.335	40.91488	38.00089

A seven-place logarithmic table was used throughout, the aim in the computations being to get the seventh significant figure correct within one or two units. The necessity for this accuracy will be seen later.

The distances, $E\ C$ and $C\ B$, are now readily derived.

For $h = 199$, $E\ C = 82.05624$, $C\ B = 51.27376$

$h = 200$, $E\ C = 82.49605$, $C\ B = 51.50395$

$h = 201$, $E\ C = 82.93577$, $C\ B = 51.73423$.

On any plane, $E\,B$, the vertical unit pressure

$$\text{at } B = p_1 = \frac{4\,b - 6\,C\,B}{b^2}\,W,$$

$$\text{at } E = p_2 = \frac{4\,b - 6\,E\,C}{b^2}\,W;$$

where $b = E\,B$, and W is the weight of masonry above the plane. This follows from the assumed "law of the trapezoid."

From these formulas we derive:

$$\text{At } h = 199,\ p_1 = 177.45483,\ p_2 = 32.22542,$$
$$h = 200,\ p_1 = 178.3855,\ p_2 = 32.24139,$$
$$h = 201,\ p_1 = 179.3160,\ p_2 = 32.25798.$$

Call p the vertical unit stress at a distance, x', from E; then

$$p = p_2 + \frac{p_1 - p_2}{b}\,x';$$

and the total stress on the base, x', is

$$P = \frac{1}{2}\,[p_2 + p]\,x' = p_2\,x + \frac{p_1 - p_2}{2\,b}\,x'^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

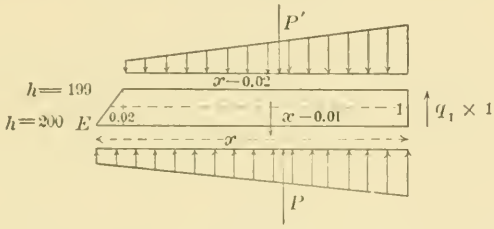

FIG. 2.

To find the unit shear on vertical or horizontal planes*, consider a slice of the dam, bounded by horizontal planes at $h = 199$ and $h = 200$, the water face and a vertical plane, at a distance, x, from the inner face (Fig. 2), in equilibrium under the water pressure acting horizontally on its left face and the forces exerted by the other parts of the dam on the slice. These forces consist of the uniformly increasing stress, P', on top, acting down; the uniformly increasing stress, P, on the bottom, acting up; a shear acting on the vertical plane at the right, of average intensity q_1 per square foot, the weight of the body

* The writer desires here to acknowledge his indebtedness to a recent paper on "Stresses in Masonry Dams" by Ernest Prescot Hill, M. Inst. C. E., published in *Minutes of Proceedings*, Inst. C. E., Vol. CLXXII, p. 134. Mr. Hill considers the case of a dam with a vertical inner face. By the aid of the calculus, he effects an exact solution, which leads to general formulas for shear and normal pressures on vertical planes.

Mr. Hill ascribes to Professor W. C. Unwin the suggestion, "that the shearing stress at any point may be found by considering the difference between the total net vertical reactions [between that point and either face] along two horizontal planes at unit distance apart," and states that Prof. Unwin "has applied the principle to a triangular dam by the use of algebraical methods."

$(x - 0.01)$, besides the horizontal forces to be given later. The vertical component of the water pressure is here neglected, as usual. The origin for x is taken, here and in all subsequent work, at the level, $h = 200$, at the inner face.

For equilibrium, the sum of the vertical components must be zero. Therefore, $q_1 = (x - 0.01) + P' - P$ .....(2)

To find P', substitute in Equation 1, $x' = x - 0.02$, $p_2 = 32.22542$, $p_1 - p_2 = 145.22941$, $b = 133.330$, giving $P' = 32.20364\ x + 0.5446238\ x^2 - 0.6442906$. For P, $x' = x$, $p_2 = 32.24139$, $p_1 - p_2 = 146.1441$, and $b = 134$; therefore

$$P = 32.24139\ x + 0.5453138\ x^2.$$

Substituting in Equation 2, we derive the average unit shear,

$$q_1 = -0.6542906 - 0.96225\ x - 0.0006900\ x^2 \ldots (3)$$

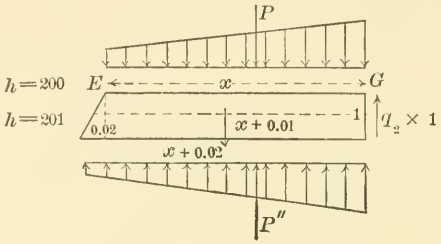

FIG. 3.

This value of q_1 is strictly correct when $x \geqq 0.02$. It is slightly in error when $0 < x < 0.02$.

A similar investigation holds to obtain the average unit shear, q_2 (Fig. 3), on a vertical plane, at a distance, x, from E, extending from the level, $h = 200$, to the level, $h = 201$.

We have, for equilibrium,

$$q_2 = (x + 0.01) + P - P'' \ldots\ldots (4)$$

We find P'' by substituting in Equation 1, $x' = (x + 0.02)$, $p_2 = 32.25798$, $p_1 - p_2 = 147.05802$, and $b = 134.67$. $P'' = 32.27982\ x + 0.5459941\ x^2 + 0.6453780$. Substituting this, and the value previously found for P, in Equation 4, we derive,

$$q_2 = -0.6353780 + 0.96157\ x - 0.0006803\ x^2 \ldots\ldots (5)$$

This is strictly correct only when $x \geqq 0$.

The mean, $\frac{1}{2}(q_1 + q_2)$, of these average shears will be assumed as approximately equal to the intensity of shear at the point, G $(x =$

E G), at the level, $h = 200$. Call q this intensity of shear on a vertical plane at *G;* therefore,

$$q = -0.6448343 + 0.96191\ x - 0.0006856\ x^2 \ldots\ldots\ldots (6)$$

Checks.—By Appendix (*b*) and (*d*), the exact value of q, at either face, $= p$ tan. ϕ, where p = vertical unit normal stress at the face and ϕ is the angle the face makes with the vertical. Thus, at the inner face, $q = -32.24139 \times 0.02 = -0.6448278$, whereas Equation 6 gives, for $x = 0$, $q = -0.6448343$.

At the outer face, the exact value is, $178.3855 \times 0.65 = 115.9506$, whereas Equation 6 gives, for $x = 134$, $q = 115.9405$.

A still more searching test can be devised. It is a well-known principle that the intensity of shear at a point, on vertical or horizontal planes, is the same [Appendix (*a*)]. Therefore, regarding Equation 6 as giving the horizontal unit shear, at the level, $h = 200$, where $b = 134$ ft.; the total shear, from face to face, on this level, is

$$\int_{x=0}^{x=134} q\, dx = 7999.75$$

This should equal the total water pressure down to the same level, $\frac{1}{5}(200)^2 = 8\,000$. Formula 6 thus gives practically exact results.

In order to find the normal unit stress on a vertical plane, we shall assume that q_1, given by Equation 3, equals the intensity of shear on a vertical or horizontal plane at the point, x, at $h = 199.5$; and that q_2, given by Equation 5, gives the shear intensity at x at $h = 200.5$. This evidently supposes that the shear intensity increases uniformly, vertically, from $h = 199$ to $h = 201$.

Consider a portion of the dam, Fig. 4, bounded by the water face; the plane, *F M*, at the level, $h = 199.5$, on which the total shear is Q', the plane, *E N*, at the level 200.5, on which the total shear is Q, and the vertical plane, *M N*, 1 sq. ft. in area, on which the average normal stress is p'. The water pressure on *E F* will be supposed to be exerted horizontally. It is equal to 80 units. Assuming, as stated, that $q_1 =$ intensity of horizontal shear at *M*, and $q_2 =$ the corresponding intensity at *N*, we have, taking the origin as before at *O*.

$$Q' = \int_{0.01}^{x} q_1\, dx\,; \qquad Q = \int_{-0.01}^{x} q_2\, dx\,;$$

or,

$$Q' = 0.006494794 - 0.6542906\ x + 0.481125\ x^2 - 0.00023\ x^3$$

$$Q = -0.00640186 - 0.6353780\ x + 0.480785\ x^2 - 0.0006803\ \frac{x^3}{3}$$

Checks.—The total water pressure for $h = 199.5$ is $\frac{1}{5}(199.5)^2 = 7960.05$ and for $h = 200.5$, $\frac{1}{5}(200.5)^2 = 8\,040.05$. The first should equal Q', for $x = 133.665$, or 7 959.22; the second should equal Q, for $x = 134.335$, or 8 041.12. The slight differences tend to give confidence in the results.

For equilibrium, the sum of the horizontal forces acting on *E F M N*, Fig. 4, must be zero;

$$\text{therefore, } p' = 80 + Q - Q' \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$p' = 80.01 - 0.0189\,x + 0.00034\,x^2 - 0.00000323\,x^3.$$

This average stress will now be assumed to be the intensity of the horizontal unit stress on vertical planes at $h = 200$.

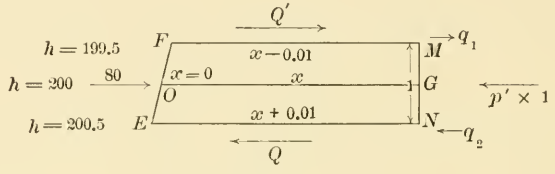

Fig. 4.

It will now be perceived why a seven-place table was necessary in the computations, the coefficients of x^2 and x^3 having only two or three significant figures in the final result. If the planes originally had been taken 0.1 ft. apart vertically, a ten-place table would have been required.

Checks.—The value of p', for $x = 0$, $p' = 80.012896$, is the same as that given by Appendix (*d*), $80 + 0.6448 \times 0.02$. When $x = 134$, the formula gives $p' = 75.81$, whereas the exact theory, Appendix (*b*), gives $p' = m^2\,p = (0.65)^2 \times 178.39 = 75.37$. The difference is 0.44 at the outer face. For any other point, it might be assumed to vary with x, so that it could be corrected by subtracting $\frac{0.44}{134}\,x = 0.0033\,x$ from the value of p' above. For ease of computation, the formula will be written,

$$p' = 80.01 - 0.02\,x + 0.00034\,x^2 - 0.00001\,\frac{x^3}{3} \ldots\ldots (8)$$

The first coefficient of x^3 cannot be counted on to the last two figures, hence we are permitted to change 323 to 333 in that coefficient. When $x = 134$, Equation 8 gives $p' = 75.41$, nearly the exact value.

The three formulas for p, q and p', at the level $h = 200$, are thus as follows:

$$p = 32.24 + 1.09063\,x.$$
$$q = -0.64 + 0.962\,x - 0.000686\,x^2.$$
$$p' = 80.01 - 0.02\,x + 0.00034\,x^2 - 0.00001\,\frac{x^3}{3}.$$

Since the weight per cubic foot of masonry was assumed as two and one-half times that of water, we must multiply the stresses given in Table 1 by $\frac{5}{2}(62.5) = 156.25$, to reduce to pounds per square foot; or by 1.085, to reduce to pounds per square inch.

TABLE 1.

x	0	10	25	50	75	100	134
p	32.24	43.15	59.50	86.77	114.04	141.30	178.39
q	−0.64	8.91	22.98	45.75	67.65	88.70	115.95
p'	80.01	80.02	79.66	79 11	79.01	78.08	75.37
max. f	80.02	82.06	94.67	128.85	166.40	203.85	253.71
min. f	32.23	41.11	44.48	37.03	26.64	15.52	0
θ for max. f	90°46′	77°06′	56°50′	42°36′	37°44′	35°12′	33°01′

In Table 1 the stresses are those experienced at the level, $h = 200$.

p = vertical unit stress on a horizontal plane,

q = shearing unit stress on horizontal or vertical planes,

p' = horizontal unit stress on vertical planes,

Max. f = maximum normal stress acting on a plane inclined to the horizontal at the angle, θ, given on the last line,

Min. f = minimum normal stress acting on a plane perpendicular to the last.

From max. f and min. f, with θ, the ellipse of stress can be drawn, and the stress in any direction, with the plane on which it acts, can be ascertained.

It will be observed that there is no tension exerted anywhere, and that the maximum compression is 253.71, or 275 lb. per sq. in., which is exerted at the outer face, parallel to that face, upon a plane at right angles to the face.

In Appendix (*e*), the important formula, for the maximum normal intensity at the outer face, acting parallel to that face,

$$f = \frac{p}{\cos.^2\phi}$$

is proved. In this instance, $p = 178.39$, tan. $\phi = 0.65$, therefore $\phi = 33°01'$, whence $f = 253.71$.

This stress is unaccompanied with any conjugate stress, perpendicular to the face. In the interior of the dam, where conjugate stresses prevail, the masonry is perhaps better able to withstand a certain compressive stress than at the face. The distribution of stresses, at the level $h = 200$, is shown in Fig. 5, on the supposition that the base of the dam is a little below that level. The connection with the foundation materially modifies this distribution; but Fig. 5 shows the distribution for sections, say, from 10 to 20 ft. above the

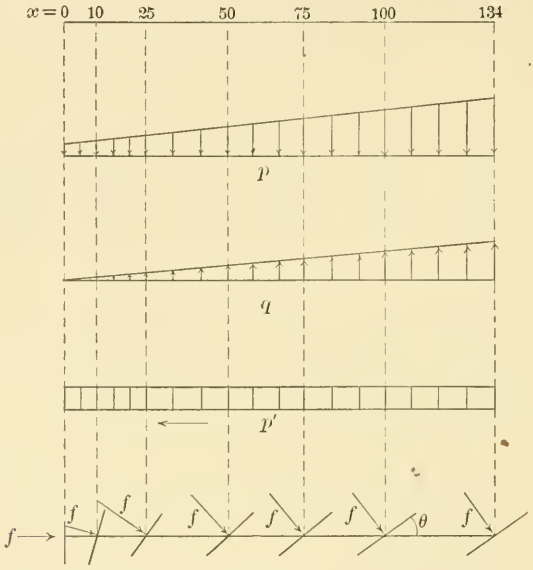

FIG. 5.

base, up to the level $h = 50$, fairly well, on the basis of the trapezoid law. As has been mentioned before, this law gives a pressure greater than the actual at the outer face.

Since the batter of the inner face is very small, the results of Table 1 should agree approximately, except near the inner face, with those found by Mr. Hill in the paper referred to in the foot-note. Substituting numerical values, Mr. Hill's formulas, for $h = 200$, reduce to

$$q = 0.9426\ x - 0.0005768\ x^2,$$
$$p' = 80 - 0.0001289\ x^2 - 0.0000009615\ x^3;$$

giving:

x	0	10	25	50	75	100	134
q	0	9.36	23.20	45.69	67.45	88.49	115.95
p	80	79.99	79.90	79.56	78.87	77.75	75.38

On comparing these formulas with those of the writer, it will be observed that the absolute term in the value of q and a consequent term of the first degree in x, in the value of p', are lacking in Mr. Hill's formulas. This results from taking the inner face as vertical. Although the coefficients also differ, it is seen that the numerical values are very nearly the same.

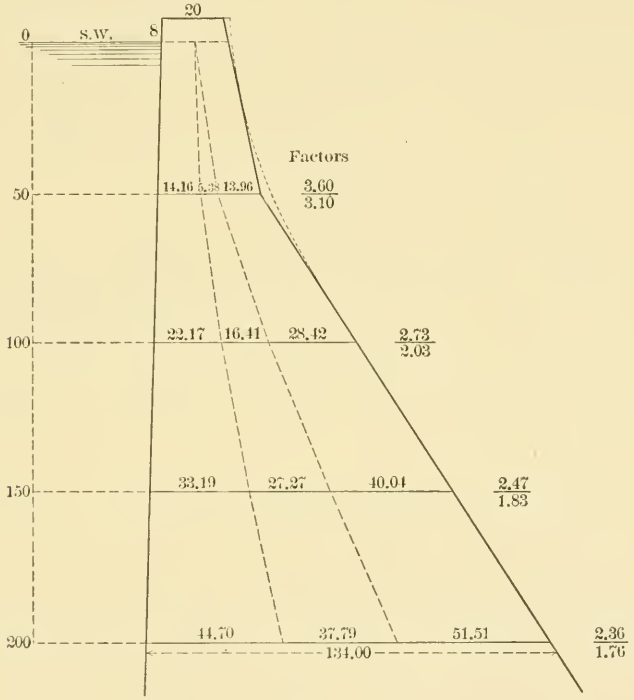

FIG. 6.

In Fig. 6 are shown, on a drawing of the dam, to scale, the lines of the centers of pressure for reservoir full and empty.

To the right, and under the word "factors," are certain numbers, written in the form of fractions. For any joint, the upper number

gives the factor against overturning, or the number by which it is necessary to multiply the water pressure down to the joint, to cause the total resultant to pass through the outer edge of the joint considered. The lower numbers give the ratio of the weight of masonry above a joint to the water pressure corresponding.

It is believed that these "factors" should increase from the base upward, to allow somewhat for earthquakes, expansion of ice in freezing, etc., since the effect of such accidental forces is proportionately greater on the upper joints.

Stresses due to water infiltration are not included here; neither are stresses due to temperature changes.

The unit stresses, f, in pounds per square inch, acting parallel to the adjacent face, are as follows, and refer to the outer edges of the joints, for reservoir full, and to the inner edges, for reservoir empty:

h,	f at outer edge,	at inner edge.
50	85	58
100	136	133
150	204	180
200	275	228

The stresses, f, are normal pressures on planes perpendicular to the respective faces, and are the greatest stresses that can be experienced in the dam. In fact, they are greater than the true stresses, since the trapezoid law is not exact, particularly near the base, as before remarked. It would then seem that the dam, thus far, is safe, since the maximum unit stress is less than concrete, even, is subjected to daily, in good practice.

For an actual construction, the outer face should be curved, from near $h = 50$ to the top, as shown by the curved dotted line in Fig. 6.

The subject of the stresses in masonry dams has caused a great deal of discussion among British engineers in the last two or three years. The subject was reopened by Mr. L. W. Atcherly and Professor Karl Pearson,* who gave the results of certain experiments which seemed to indicate considerable tension across vertical planes near the outer toe. The late Sir Benjamin Baker, Hon. M. Am. Soc. C. E., also published† the results of experiments on a model dam of stiff jelly, and very recently, the "Experimental Investigations" of Sir J. W. Ottley

* *Minutes of Proceedings*, Inst. C. E., Vol. CLXII, p. 456.
† *Ibid*, Vol. CLXII, p. 123.

and Mr. A. W. Brightmore* on elastic dams of "plasticine" (a kind of modeling clay) and the experiments of Messrs. J. S. Wilson and W. Gore† on "India Rubber Models" have been presented.

It is not the object of this paper to discuss these later experiments; but it may be remarked that they show very plainly that no tension exists near the outer toe, but that tension does exist at the inner toe, where the dam is joined to the foundation, and it has become a serious matter how to deal with it. The influence of the foundation in modifying the distribution of the stresses at the base of the dam was found to be very great, causing the shear there to be more uniform than higher up, where the parabolic law, nearly as given by the formulas above, was found to hold. Also, above some undetermined plane, a small distance above the base, the usual "law of the trapezoid" was found to be approximately correct, leading to stresses on the safe side at the outer toe. This law leads to stresses at the outer toe of the base considerably in excess of the true ones.

It was found, from the rubber models particularly, as theory indicates, that the greatest normal pressures are exerted at the downstream face, for reservoir full, and they act in a direction parallel to that face.

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* *Ibid*, Vol. CLXXII, p. 89.
† *Ibid*, Vol. CLXXII, p. 107.

APPENDIX.

Relations Between Stresses at any Point of a Dam.

(*a*).—Consider a cube of masonry, Fig. 7, the edge of which has the length, a, bounded by vertical and horizontal planes and subjected to normal and shearing forces, caused by the action of the other parts of the dam. Since a will be supposed to diminish indefinitely, the weight of the cube, which is proportional to a^3, is an infinitesimal of the third order, and can be neglected in comparison with the normal forces, which vary as a^2 and are thus of the second order.

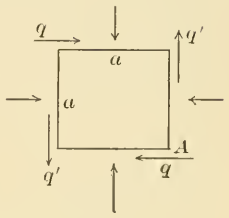


Fig. 7.

Similarly, the average unit stresses exerted on the faces can be treated from the first as the unit stresses at any point, A, of the cube. As a diminishes indefinitely, the oppositely directed normal forces approach equality and balance independently; hence the couples formed by the shears on opposite faces must likewise approach equality; the one being right-handed, the other left-handed; therefore $q\ a \times a = q'\ a \times a$, or $q = q'$; hence, the intensities of shear at a point on two planes at right angles are equal. The relative directions of the shears on two planes at right angles are determined, as above, from the consideration that one resulting couple must be right-handed and the other left-handed. This applies also to Figs. 8 to 11.

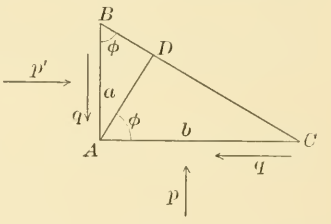


Fig. 8.

(*b*).—In Fig. 8, $A\ B\ C$ is the right section of a prism at the outer face, with lateral faces one unit in length, perpendicular to the plane of the paper.

Let $A\ B$ be vertical; tan. $\phi = m$, a constant;

p = normal intensity on a horizontal plane at C,

p' = normal intensity on a vertical plane at C,

q = shear intensity on horizontal or vertical planes at C.

The weight of the prism is $\frac{1}{2}\ a\ b$.

Balancing vertical as well as horizontal components, we have, when $a = A\ B$ and $b = A\ C$ are very small,

$$p\ \ b = q\ a + \frac{1}{2}\ a\ b, \text{ nearly;}$$
$$p'\ a = q\ b.$$

Dividing the first equation by b, the second by a, the limit, as a and b approach zero, gives exactly,

$$p\ = q \text{ cot. } \phi, \text{ therefore } q = m\ p,$$
$$p' = q \text{ tan. } \phi, \text{ therefore } p' = m^2\ p,\ p\ p' = q^2.$$

These equations give the relations between p, q and p' at the outer face. The same relations hold at the inner face, for reservoir empty, on replacing ϕ by ϕ', the angle the inner face makes with the vertical.

For the remaining cases, the final limits will be written at once, since the complete process of deriving them is evident from the above. In fact, the weight of the prism, $\frac{1}{2}\ a\ b$, being of the second order, can be neglected in comparison, with $q\ a$, etc.

(c).—For reservoir full, calling $w = \frac{2}{5}\ h$, the intensity of water pressure, horizontally or vertically, at C, we have at the inner face, putting tan. $\phi' = n$, Fig. 9,

$$p\ b = q\ a + w\ b;\ p'\ a = q\ b + w\ a;$$

therefore $\quad p = \frac{1}{n}\ q + w;\ p' = q\ n + w.$

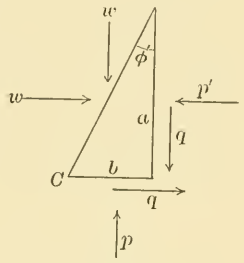


Fig. 9.

(d).—If the vertical component of the water pressure is neglected, these equations reduce to

$$p = \frac{1}{n}\ q;\ p' = q\ n + w;$$

therefore $\quad q = p\ n,\ p' = n^2\ p + w.$

(e).—Since the shear on the outer face is zero, therefore, by (a), the shear on a plane, $A\ D$, Fig. 10, perpendicular to the outer face, is also zero, or the stress on $A\ D$ is normal.

Call f the intensity of such a stress at C. The total pressure on $A\ D = f \times A\ D = f\ b$ cos. ϕ, and its vertical component is $f\ b$ cos.$^2\ \phi$, therefore balancing the vertical components,

$$p\ b = f\ b \text{ cos.}^2\phi;$$

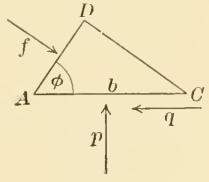


Fig. 10.

therefore $$f = \frac{p}{\cos.^2 \phi} = p \sec.^2 \phi$$

This is a most important formula for finding the maximum normal intensity at the outer face. It applies equally to the inner face for reservoir empty, on changing ϕ to ϕ', the angle the inner face makes with the vertical. For either face, p is the vertical normal unit stress at the face considered.

(f).—Principal Normal Stresses at Any Point in the Dam and the Planes on Which They Act.—In the prism, $A\ B\ C$, Fig. 11, let $A\ B$ be one of the planes on which the stress is normal. Let f be its intensity. The stress on the plane, $A\ B$, of unit length perpendicular to the plane of the paper, is thus $f\ c$; its vertical component is $f\ c$ cos. $\theta = f\ b$, and its horizontal component is $f\ c$ sin. $\theta = f\ a$, θ being the angle that $A\ B$ makes with the horizontal.

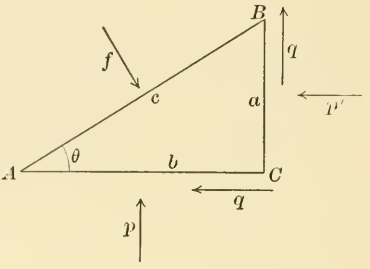


Fig. 11.

Place the sum of the vertical forces acting on $A\ B\ C$ equal to zero; also place the sum of horizontal forces equal to zero.

$$f\ b = p\ b + q\ a, \text{ therefore } f - p = q \text{ tan. } \theta,$$

$$f\ a = q\ b + p'\ a, \text{ therefore } f - p' = q \text{ cot. } \theta.$$

The difference of the last two equations gives

$$p - p' = q\ (\text{cot. } \theta - \text{tan. } \theta) = q\ \frac{1 - \text{tan.}^2\ \theta}{\text{tan. } \theta},$$

therefore tan. $2\ \theta = \dfrac{2 \text{ tan. } \theta}{1 - \text{tan.}^2\ \theta} = \dfrac{2\ q}{p - p'}$.

The angles, θ (differing by 90°), computed from this equation, give the directions of the planes, $A\ B$, on which the stress is entirely normal.

From an equation above, we likewise have

$$\text{tan. } \theta = \frac{f - p}{q}.$$

This gives directly the plane on which a given f acts.

To deduce a formula for f, take the product of two equations above:

$$(f - p)\ (f - p') = q^2,$$

therefore $f = \dfrac{1}{2}\ [p + p' \pm \sqrt{(p + p')^2 - 4\ (p\ p' - q^2)}]$.

This equation gives the two values of f corresponding to the two planes mentioned; compressive when f is positive, tensile when negative. There can be no tension when $p\ p' \geqq q^2$.

A better form for computation is,

$$f = \frac{1}{2}\,[p + p' \pm \sqrt{(p - p')^2 + 4\ q^2}].$$

DISCUSSION

Mr. Walker. E. G. Walker, Jun. Am. Soc. C. E. (by letter).—This paper is chiefly of interest as an arithmetical exposition of a practical method of treating the question of the design of masonry dams which has been developed by engineers during the last few years. The fundamental basis of the theory is simple, and, as far as the question of stresses in the body of the dam is concerned, is sufficiently accurate for use in designing these structures, for, as Professor Cain states, any discrepancy which exists between it and the results of experiments is on the side of safety. This theory also follows as a logical development of the older "middle third" rule, which remained unchallenged for so long; but within recent times a mathematical theory, obtained by basing calculations on doubtful hypotheses, as to initial conditions, was developed, which purported to call into question the safety of dams designed on the older theory.

Fortunately, failures of large masonry dams have been sufficiently rare to preclude obtaining much direct experimental evidence as to the causes of failure under working conditions. It is a fact worthy of notice, however, which has been pointed out by Dr. W. C. Unwin, that investigation of the only two cases of failure of high masonry dams in recent years which have been attributable to faulty design, namely, those of the Bouzey Dam in France in 1895, and the Habra Dam in Algiers, has shown that in both instances the conditions laid down in the "middle third" rule have not been complied with. This would point to the conclusion that, whatever new lines of argument may be developed now or in the future, engineers cannot afford to disregard this method of analyzing the distribution of stresses, as it leads to the trapezoidal law of distribution on a horizontal plane. As a sort of negative deduction, it follows that, in extending further our ideas of these internal stresses, it is desirable to proceed on the basis established by the older theory, from which it may be hoped to get a nearer insight into the nature and disposition of the actual stresses which are set up in a dam.

The method used in the paper is a development of the principle which, the writer believes, was first enunciated in connection with dams by Dr. W. C. Unwin, in a letter entitled "Notes on the Theory of Unsymmetrical Masonry Dams."* In this letter, Dr. Unwin shows how, by assuming the trapezoidal law of distribution of direct stresses on horizontal sections, the distribution of shear immediately follows by a simple process of reasoning. It may be of interest to place on record in the *Transactions* of the Society an outline of this reasoning.

Dr. Unwin, for simplicity of discussion, considers in the first instance the case of a simple triangular dam, but, as the reasoning is

* Published in *Engineering* (London), April, 1905.

independent of the form of the profile, it may be applied to any section, as, for example, that used by Professor Cain in his calculations. In later discussions, by the same writer, more complex sections are considered in detail. Mr. Walker.

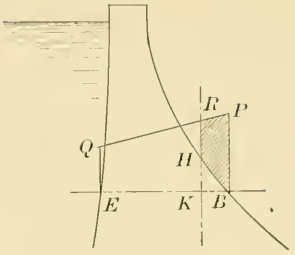


Fig. 12.

By proceeding in the usual way, we can arrive at the trapezoidal distribution of stress on any horizontal section of a dam EB (Fig. 12), indicated diagrammatically by $EQPB$, the magnitudes of BP and EQ being given respectively by the formulas arrived at on page 211:

$$p_1 = \frac{4\,b - 6\,C\,B}{b^2}\,W$$

$$p_2 = \frac{4\,b - 6\,E\,C}{b^2}\,W$$

In this analysis, the stresses are for convenience considered as measured in masonry units.

Now consider any vertical section HK. The forces acting on the down-stream side of HK are:

(1) The weight of section, HKB, acting downward;

(2) The upward reaction of the section of the dam below BK, acting upward.

No. 1 is represented by the area, HKB, and, by a suitable choosing of the scale, No. 2 is represented to the same scale by the area, $BPRK$. Hence the shear on HK, which must balance the difference of these forces, is represented by the hatched area, $BPRH$.

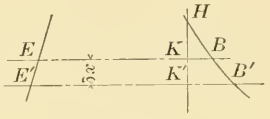


Fig. 13.

Next, by taking two sections, EB, $E'B'$, close together (Fig. 13) we can determine successively the shears, S and $S + \delta S$, on HK and HK', respectively. Then we get, by difference, the mean intensity of shear stress on $KK' = \frac{\delta S}{\delta x}$ and, as the horizontal shear at any point is equal in magnitude to the vertical shear at that point, the horizontal shear at $K = \frac{\delta S}{\delta x}$. The stress at any point of the section is thus completely defined, for, knowing the direct stress and the shear stress at any point, it is an easy matter to calculate the intensities and directions of the maximum and minimum stresses at that point by the ordinary mechanical principles set out in Section f of the Appendix.

Mr. Walker.

The result of this reasoning is given on page 212 to get Equations 2, 3, and 4, giving the distribution of shearing stress on various sections. As mentioned on page 211, it was applied by Dr. Unwin to the case of a triangular dam with the crest at top water level. In a second letter, entitled "Further Notes on the Theory of Unsymmetrical Masonry Dams"* he develops the following simple equations for the shear at any point on a horizontal section, EB (Fig. 14), of a dam of this type: Considering a section of the dam of unit length, the average shear at a point distant x from E, is

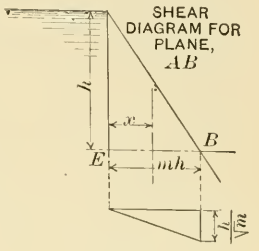


FIG. 14.

$$S_x = x\left(\frac{3\,k}{m} + \frac{1}{2}\right)$$

where k is a constant

$$= \frac{1}{3}\left(\frac{1}{\gamma\, m} - \frac{m}{2}\right)$$

γ being the density of masonry relative to water, and m the ratio of the height of the dam to the breadth.

Hence, in this case, the distribution of shear over the section is triangular, as shown in the shear diagram, Fig. 14, the maximum value at B being

$$S_B = m\,h\left(\frac{3\,k}{m} + \frac{1}{2}\right)$$

$$= h\left(\frac{1}{\gamma\, m} - \frac{m}{2}\right) + \frac{m\,h}{2}$$

$$= \frac{h}{\gamma\, m}$$

The total horizontal shear on $EB = \int_o^{mh} S_x\, dx$

$$= \frac{1}{2}\, m\, h\, \frac{h}{\gamma\, m} = \frac{h^2}{2\,\gamma}$$

that is, it is equal to the total horizontal water pressure down to the level, EB.

This, of course, is the simplest case of the application of the principle. The analysis of more complicated profiles naturally leads to more complicated equations. The generalization for any section has been worked out analytically by Mr. E. P. Hill in the paper referred to by the author. By the use of the calculus, Mr. Hill is enabled to arrive at the actual intensity of shear at any point, K

* Published in *Engineering*, May, 1905.

(Fig. 13), by bringing the two planes, *EB, E'B'*, indefinitely close together. He thus obtains the equations referred to by the author, from which by substitution the equations given on page 216 are obtained. Mr. Walker.

The author reaches the same end by a slightly different method. In order to obtain a possible arithmetical treatment, the horizontal sections which Mr. Hill brings ultimately indefinitely close together must be kept at a definite distance apart. In the present case the distance is a foot, so that the distribution of shear at a depth of 200 ft. below top water level is considered as a mean of the distributions obtaining at 199.5 ft. and 200.5 ft. This, of course, introduces a discrepancy between the author's results and the results to be expected from Mr. Hill's formulas; but, by using such a narrow strip (in this case, only one-two hundredth part of the head of water), any arithmetical difference on this score should be reduced to a minimum. Hence the agreement should be very close, and, as the author points out, this is the case, any difference which actually occurs being due to the difference of the profile of the up-stream face, which latter, in Mr. Hill's investigation, is not taken into account, being assumed as vertical.

Therefore it occurs to the writer to ask whether it would not be easier, when investigating in detail any particular profile, to take Mr. Hill's formulas and substitute for the variables in them, rather than go through the laborious arithmetical process which the author details in his paper, the tediousness of which is increased by the great degree of accuracy to which he finds it necessary to carry his computations. For it must be borne in mind that the calculations given apply only to one section of the dam, namely, that at 200 ft. depth, and it would appear that, if any other section is to be investigated, a new set of calculations would have to be made. It would be of interest if the author would state whether he has investigated the possibility of devising a mode of calculation which would avoid the necessity of recalculating from first principles for every horizontal section considered. It would appear, *prima facie*, that, when the profile is continuous, that is, when there is no sudden change of curvature of the faces such as occurs for example at the 50-ft. level in the dam shown in Fig. 6, it should be possible to get the stress equations for one level directly from those of another by a suitable variation of the constants according to a determinable law. If such a scheme were feasible, a good deal of arithmetical labor would be saved. In other words, the three formulas for direct and shear stresses may be put in the general forms:

$$p = \alpha + \beta x$$
$$p' = \gamma + \delta x + \varepsilon x^2 + \zeta x^3$$
$$q = \eta + \theta x + k x^2$$

Mr. Walker.

For a continuous profile, each of the quantities, α β. . . . k, would vary with the depth according to some law more or less complex. Once these functions are obtained, it would then be a straightforward matter to substitute for the particular depths required and get the various stress equations.

The author states on page 218 that stresses due to infiltration and temperature variation have not been considered. It is hardly possible to consider these theoretically. As to the latter, they would most probably act chiefly in a direction at right angles to the plane of the stresses which have been considered in the paper, and therefore will not influence the distribution of these latter very greatly.

There is one matter which, unfortunately, is only cursorily touched, and is not discussed in the paper, though it is one of the most important points to which recent investigations and discussions on masonry dams have directed attention. Although the question at one time raised, as to the existence of tensile stresses at the down-stream toe, appears to have been settled in the negative, there still remains the fact that the experiments on models have indicated the existence of similar stresses at the up-stream toe at A, Fig. 15. With the exception of the investigation of Messrs. Atcherly and Pearsons, which cannot be fully accepted, no theoretical solution, as far as the writer is aware, has been advanced which will indicate the nature of the stresses at this point. Dr. Unwin has discussed the distribution of stress on a horizontal plane, PQ, Fig. 15, below this level, and has concluded that at a depth great enough to be uninfluenced by the discontinuity of section where the superstructure joins the base, the distribution of shear probably approximates to a parabolic law; but he gives no solution for the stresses in the neighborhood of AB, and it would be of interest to have the author's opinion as to the possibility of obtaining a result in this case. If the presence of tensile stresses of a measurable degree of intensity were fully proved, it would no doubt have great influence on the design of this part of the structure, and therefore any investigation which could throw any further light on the stresses at the plane of junction would be of advantage in clearing up this point.

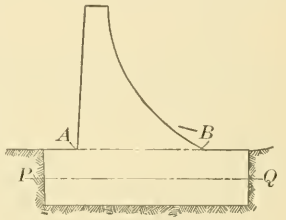


FIG. 15.

In conclusion, the writer would point out an arithmetical check which the author appears to have passed over, although recognizing the principle of it. On page 216, in discussing the stresses at the face of the dam, he states: "This stress is unaccompanied by any conjugate stress perpendicular to the face." This is, of course, essential, as there

are no external forces acting on the down-stream face. Hence, any deviation from this condition in the results obtained at once indicates an error of calculation. Mr. Walker.

WILLIAM CAIN, M. AM. SOC. C. E. (by letter).—The writer is glad that Mr. Walker has brought out the fundamental principles at the base of Dr. Unwin's discussion of triangular dams. Dr. Unwin himself has recently stated,* apropos of his treatment, that "He did not know it when his own Papers were written, but he learned soon after that by a different analytical method, Mr. Levy in France had previously arrived at exactly the same conclusions." As the writer has not seen either Dr. Unwin's or Mr. Levy's papers on dams, he was only able (in the footnote, p. 211) to acknowledge his own indebtedness to Mr. Hill, quoting him further in giving certain credit to Dr. Unwin, which is now made clear by Mr. Walker's discussion. In the latter, it will be seen that the method given for finding shear involves the same principle as the method given by the writer, which follows more nearly Mr. Hill's treatment; however, the stress at any point is not completely defined, "knowing the direct stress and the shear stress," as Mr. Walker suggests, for by Section (*f*) of the Appendix, three of the quantities, p, q, p', θ, and f, must be known to find either of the other two. Hence expressions for p, q, and p' were obtained by the writer to effect a complete solution. Mr. Cain.

With regard to the practicability of finding general formulas for q and p' for any section, the writer will say that, for a battered up-face, the attempt led to formulas of such inordinate length that it was abandoned.

The object of the discussion was to show the variation of stress, and particularly to deduce maximum stresses, which are of special interest to the practical designer, though it is well for him to be assured, once for all, that certain formulas give maximum stresses. For many years, the ordinary procedure has been to compute p at the outer toe and use a limiting safe stress for p as found from an investigation of stable dams which have lasted perhaps for centuries. Rankine called attention, years ago, to the fact that p was not the maximum stress at the toe; but that the maximum stress at the face acted parallel to the face on a plane at right angles to it and was greater than p in a certain ratio which he allowed for empirically.

Dr. Unwin, in discussing Mr. Hill's paper,† states that he deduced the formula, $f = p \sec.^2 \phi$, in 1905 (see Section (*e*) of the Appendix), for this maximum stress at a face, but adds that Levy must be credited with its first derivation. In several old dams which have lasted for centuries, the values of p ranged from $11\frac{1}{2}$ to 14 tons per sq. ft., accord-

* *Minutes of Proceedings*, Inst. C. E., Vol. CLXXII, Part II, p. 161, Discussion of papers by Hill and others.

† *Minutes of Proceedings*, Inst. C. E., Vol. CLXXII, Part II, p. 134.

Mr. Cain. ing to Unwin, giving the maximum compressive stresses, $f = p \sec.^2 \phi$, from 15 to 20 tons per sq. ft. (234 to 311 lb. per sq. in.).

As to the use of Mr. Hill's equations, referring to a dam with a vertical up-stream face, for studying variation of stress, the comparison of numerical results shows that they can be used to give quite close results when the up-stream face is battered only slightly. The equations are necessarily very long, and the applications tedious. It will be observed that the method used by the writer leads always to equations for p, q and p' of the first, second, and third degrees in x, respectively, exactly as in Mr. Hill's formulas.

Another subject touched on by Mr. Walker—that of tension at the up-stream toe of a dam—has not been attempted theoretically; for there is not only discontinuity in the profile there, but likewise in the material, where the dam joins the foundation.

Experiment has been appealed to, and, especially in the paper on India rubber models, by Messrs. Wilson and Gore,* the engineer will meet with much of great practical value, given in a very complete manner. Tension was invariably found in the foundation about the up-stream toe. Such tension is easily explained when it is considered that the horizontal pressure of the water against the dam must be resisted by the foundation; an elastic yielding or movement down stream of the foundation at the base of the dam follows, which necessarily causes tension in the part of the foundation just above the dam. This, in turn, causes irregularity in the distribution and (perhaps) in the character of the stress at the inner toe of the dam. Where, as is usual, a large amount of earth is placed over the inner toe, the added weight causes just so much compression on the inner toe, and doubtless helps to counteract the tendency toward tension. It may be added that there is no recorded instance of a dam having failed from such tension in the foundation.

* *Minutes of Proceedings*, Inst. C. E., Vol. CLXXII, Part II, p. 107.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1108

THE OPERATION OF PASSENGER ELEVATORS.*

By Reginald Pelham Bolton, M. Am. Soc. C. E.

With Discussion by Messrs. F. Lavis, Robert Brewster Stanton, William J. Boucher, and Reginald Pelham Bolton.

The subject of the conveyance of passengers to and from the floors of high buildings is one in which the public of New York City, by reason of the city's peculiar physical conditions, has a particular concern, and in which there is much of interest for residents in other cities, as well as for members of the Engineering Profession.

The great increase in the number of high buildings in the metropolis within the last decade is evident to any casual observer, more than 500 buildings exceeding 125 ft. in height having been erected within a period of less than 20 years. In these, and in other buildings of less height, many thousands of elevators are in operation, carrying a traffic far exceeding in numbers the passengers on all the railroads of the Greater City, and reaching a very large total distance of daily travel.

Between June 1st, 1903, and January 1st, 1908, there were erected, in the down-town district, south of Chambers Street, office buildings having a total occupied area of 3 157 596 sq. ft., and affording, on an average occupancy of 1 person to 130 sq. ft. of rentable area, space for a business population of 24 000 persons. Nearly all this space in business and office buildings is at an average height exceeding 13 floors above the ground, and it may be estimated that not less than 188 elevators are required to accommodate this tenancy.

* Presented at the meeting of February 17th, 1909.

In the lower part of the Borough of Manhattan there are now twenty-six buildings which exceed 17 stories in height, and their occupied or rentable area above the ground floor amounts to about 5 044 630 sq. ft. There are 266 elevators in these twenty-six buildings, and their average travel is 4 400 miles per 8-hour day, their passenger-carrying capacity being 2 896 000 persons in 8 hours.

The Department of Buildings reports the existence, in the Borough of Manhattan alone, of 9 000 passenger elevators and 12 000 freight machines. During the past six years more than 4 000 elevators have been installed in this area; and between 1903 and 1907, about 9 725 921 sq. ft. of rented area has been added in business buildings, 10 965 837 sq. ft. in lofts and stores, and 3 178 248 sq. ft. in factories, a total of 23 870 006 sq. ft., or about 550 acres.

In the business buildings alone this may be assumed to provide accommodation for about 65 000 persons, a rate of increase of about 13 000 persons per year, who depend upon elevators for access to and from their places of business.

Such an important adjunct to the operations of modern business as the passenger elevator has thus become, connected so directly with the comfort and convenience of the public, as well as the prosperity and value of immense property interests, deserves a closer degree of attention than has been hitherto bestowed upon its operation, and some study of the conditions which in this form of transportation have proven so successful, as compared with the failure of transportation methods in the horizontal direction, will not be unworthy of consideration by the Society.

Elevators, like railroad trains, are appliances which operate in combination with the human element making use of the mechanical features.

The reciprocation of elevators and of trains, if they should be conducted without reference to passengers, might afford a maximum amount of operation with a minimum of utility. Their movements within any given period of time are reduced and limited by the time introduced into their operation, by passengers entering, riding in, and leaving the appliance.

It will be seen, as the study of the operating conditions of elevators proceeds, that they are subject to much the same limitations as in the case of the operation of railroad trains and surface cars. A large building equipped with a bank of elevators, operated on a schedule

system, is practically a short-distance railroad, having stations only a few feet apart. The mere fact of the travel being vertical, has little bearing on the comparison, as it is simply a question of power operating in one direction adversely to gravity, while the force of gravity is utilized in the reverse direction.

The limitations before referred to are less connected with the designed speed of the apparatus than with the time occupied by the human freight in utilizing the appliance. As in surface transportation, it is not the alert and active passengers, but the slow and stupid ones who bring about the delays, aggravated in both forms of transit by ill-designed means for admitting of the passage of these persons to and from the vehicle. As one obstructive person can delay the movement of a train from a station, and thereby hinder all trains following on the same track, so the actions of one person in one elevator will affect the operation of others running on a "schedule," notwithstanding the fact that each elevator possesses its own independent line of travel.

Where too large a traffic is imposed upon an elevator or set of elevators, a delay will result, not only in time occupied in handling those persons, but in an additional loss of time due to crowding and pushing past one another. This is exactly what is occurring to-day in surface transit, and, as a result, the designed operation of trains or elevators is modified, and to a great extent fixed, by the conditions set up by the passengers.

An attempt to carry in any elevator an undue number of persons per trip brings about delay and less satisfactory service, and results in a less number of persons being carried per hour. A maximum of convenience and efficiency is attained, when, with intelligently designed means of ingress and egress from the cars, an average number of persons is carried per trip each way, bearing the relation to the floors which are served, of four persons to ten floors.

The passenger elevator is an appliance having designed limitations of motion, and certain capacities for lifting and lowering live loads in its cars, up to a maximum, at predefined speeds. The variation introduced into its operation by varying loads is not only a modification of traveling speed, but of the time which is occupied in the acceleration of the car from a state of rest to that speed, and of its retardation from that speed to a state of rest.

These modifications also vary in the two directions of travel, for on the up-run the force of gravity is adverse to the load and to its acceleration, but is in favor of its retardation, while gravity acts in the reverse way regarding each upon the down-run of the car. The effects of gravity may be modified by balancing or counterweighting, but the modification merely distributes the effects between the live load and the counterweight, and cannot usefully be extended much beyond the average live load.

Very considerable variations, therefore, may exist between different elevators, not only in the matter of speed with different loads, but in capabilities of acceleration and retardation at various loads; and the efforts of designers have been very properly directed toward bringing about the most economical as well as effective combination of lifting power, speeds, and retardation over the range of loads, from the full capacity of the car to that of a car containing only the operator.

As the operations of starting and stopping are necessarily exercised at very frequent intervals, the capabilities of the apparatus in these functions may be of greater importance than running speed. Thus a machine having a certain car-speed with a corresponding live load, is exercising that particular speed only over such part of the distance of the travel of its car as remains over and above the distances occupied in the process of acceleration and retardation.

The point may be illustrated thus: A car serving 15 floors above the ground floor, travels, say, 384 ft., making 7 stops each way, or 16 separate flights. It has the ability to accelerate and retard its average speed in 10 ft., occupying a period in each such operation of 2.4 sec. It will thus occupy $2.4 \times 16 = 38.4$ sec., and the distance covered in this period, is $10 \times 16 = 160$ ft. The remainder of the distance, or 224 ft., is covered (at a designed traveling speed of 500 ft. per min.) in 26.9 sec. If the traveling speed were 600 ft. per min.. with similar acceleration and retardation, the only gain would be $4\frac{1}{2}$ sec. on the whole trip, so that, to afford any substantial advantage, the faster machines must also decrease the time of acceleration and retardation. Mere increase of running speed, where stops are frequent and flights are correspondingly short, does not show commensurate advantage.

Since the functions of acceleration and retardation thus occupy so important a part of the operation of any elevator, it is evident that

operating conditions which bring about the increase of the number of such functions, and the consequent reduction of the distance in which the real speed of the appliance can be exercised, are of great importance.

If an elevator be charged with traffic so that its operation involves a stoppage at every floor, which in business buildings may be taken to be commonly arranged at a distance of 12 ft. apart, then there is no time in which, with an average distance of acceleration and retardation of, say, 15 ft., its designed speed would come into play. A machine having a speed of 8.33 ft. per sec., would, in point of fact, develop only an average speed of 3.73 ft. per sec.; but if the traffic were related to the elevator in such a way (or rather, if the number of elevators were so adequate for the traffic) as to require stops at intervals or flights of two floors, or say, 24 ft., the mean speed would rise to 5.13 ft. per sec., and the gain in the round-trip time in a 16-story building would be 28 sec., a substantial saving of nearly half a minute.

Fig. 1 shows the curves of mean speeds, in feet per second, resulting from functional distances of 10 and 15 ft., and a traveling speed of 500 ft. per min., at various intervals or flights, up to 30 ft.

The speed of a passenger elevator is thus seen to be closely related to the traffic which is imposed upon it. If that traffic be such as to increase the number of stops, and so to reduce the average flights of the car below a distance required for corresponding acceleration and retardation, then the speed capability of the machine is not exercised at all, and the mean speed is reduced in proportion to the increase of traffic.

In a recent book on elevator service by the writer, the statement is made that when carrying more than a certain number of persons per trip an elevator would actually fall off in traffic. This result can be readily comprehended when it is realized that excess of load involves, not only a decrease of traveling speed, but also an increase of the distances required for acceleration and retardation, all involving losses of time.

The loads, traveling speeds and stopping distances, observed by J. R. Furman, M. Am. Soc. C. E., on the powerful hydraulic elevators installed in the Hanover Bank Building, in the City of New York, afford an excellent and authentic instance of the variations introduced into the operation by increasing loads, and are plotted in Fig. 2,

together with the curves of distances for acceleration and retardation, from a live load of 180 lb. to one of 3 600 lb., or say, from the weight of the operator alone, up to a weight corresponding to about 25 passengers and the operator.

Applying the capacities of such a machine to the service of twenty-five floors above the ground floor, the mean speed between stops will be varied by the load and the distance between stops required by that load, as shown in Table 1.

TABLE 1.

Load, in pounds	1 000.	1 500.	2 000.	2 500.	2 700.	3 000.	3 400.	3 060.
Corresponding passengers	7.	10.7	14.	17.	19.2	21.4	24.2	25.7
Relation of passengers to floors served	0.28	0.42	0.56	0.72	0.77	0.85	0.97	1.02
Corresponding flights, in feet	43.	30.	21.5	17.	16.	14.	12.	12.
Average speed between stops	653.	574.	454.	352.	325.	285.	210.	175.

These results give a curve of passengers per hour, plotted in Fig. 3, corresponding to passengers per trip. The hourly traffic carried increases rapidly, until the point is reached where the relation of passengers to floors served is as 4 to 10, then it increases at a reduced rate, until the relation of 6 to 10 is reached, and then it decreases.

When a relation of one person to each floor is reached, the traffic per hour is no more than that when about 3.5 persons per trip are carried.

These figures also show that the 4 to 10 traffic is 94% of the maximum attainable, and that this amount is carried in 60% of the time of the maximum.

The difference in favor of the 4 to 10 relation is even more marked when one-way hourly traffic is computed, as in the small upper curve, which shows that when running on the 4 to 10 basis all one way, very nearly the maximum travel is attained, and that an elevator to which had been apportioned a greater amount of traffic, would fall off very considerably in hourly traffic capacity.

The developments of elevator travel have brought about a general demand for a convenience in point of time which is represented by an effective service within a period of about 3 min. for a round trip; therefore, it becomes very desirable to determine the amount of traffic which shall be apportioned to an elevator, and thus learn what imposi-

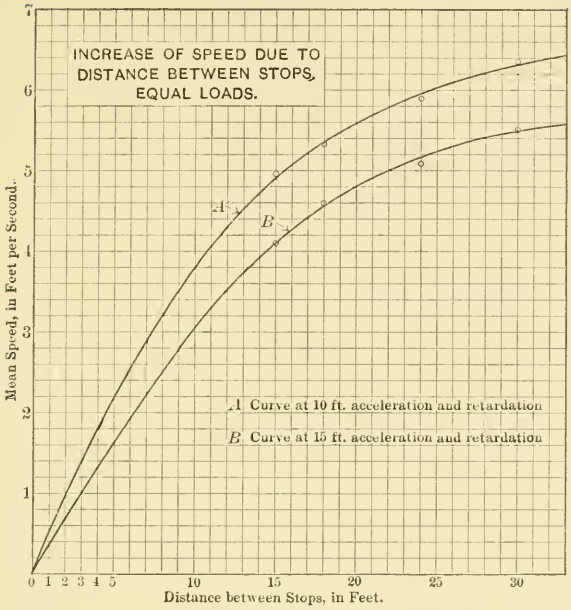

INCREASE OF SPEED DUE TO DISTANCE BETWEEN STOPS, EQUAL LOADS.
A
B
A Curve at 10 ft. acceleration and retardation
B Curve at 15 ft. acceleration and retardation
Mean Speed, in Feet per Second.
Distance between Stops, in Feet.

FIG. 1.

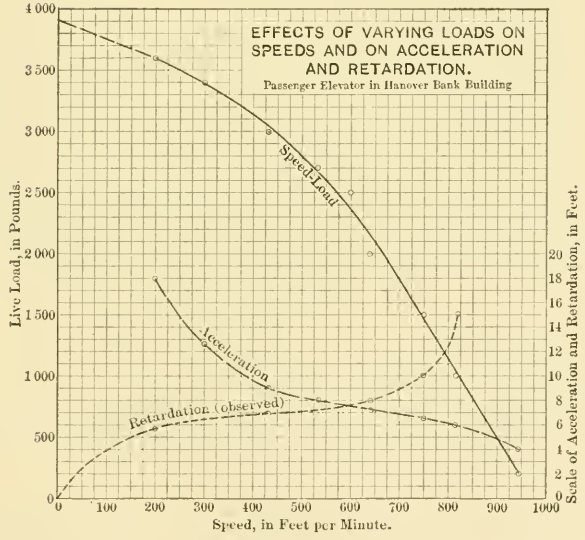

EFFECTS OF VARYING LOADS ON SPEEDS AND ON ACCELERATION AND RETARDATION.
Passenger Elevator in Hanover Bank Building
Speed-Load
Acceleration
Retardation (observed)
Live Load, in Pounds.
Scale of Acceleration and Retardation, in Feet.
Speed, in Feet per Minute.

FIG. 2.

tion of live load and corresponding limitations of flight are to be introduced into its duty.

In the past, the former of these two elements has been rather loosely assumed by designers to be represented by an average of from 40 to 50% of the car capacity of an elevator. The lack of definiteness in this assumption is apparent. Cars may be and are of all sizes, due to eccentric conditions of the building, or to the personal views of

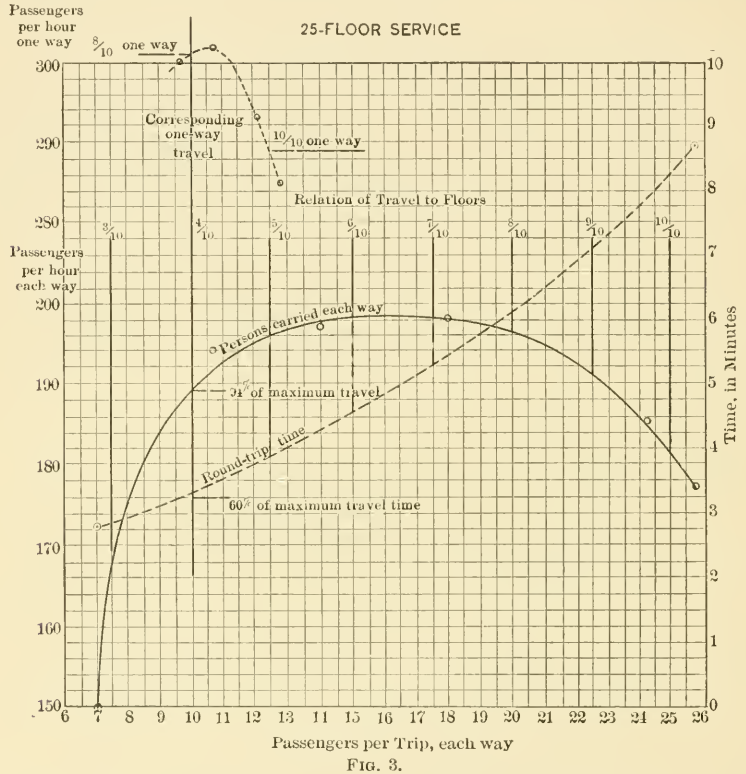


FIG. 3.

architects, their capacity for passengers bearing no relation to the developed traffic. A large car designed to operate under conditions of 40% of its full load may be allotted traffic averaging 80% or 20%, involving a totally different condition from that for which it was destined.

As to the time occupied in passenger movement in the foregoing computations, and in Fig. 3, the observations published elsewhere by

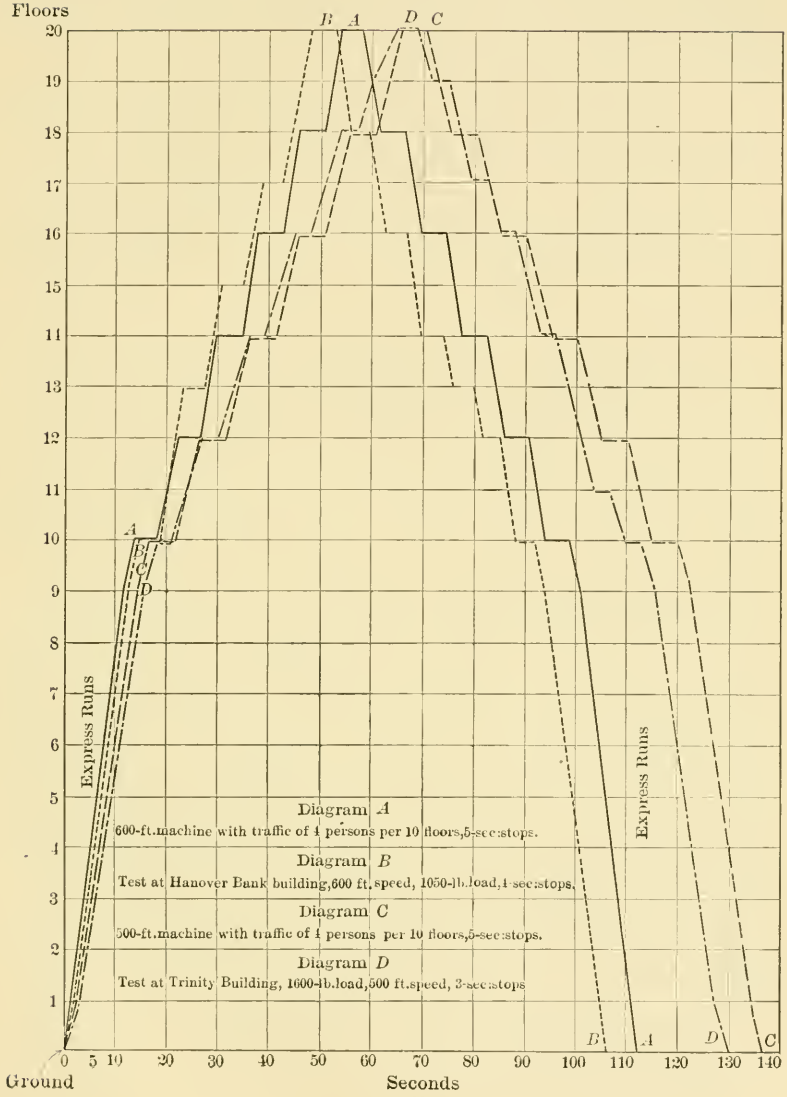

Floors
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Ground
0 5 10 20 30 40 50 60 70 80 90 100 110 120 130 140
Seconds
Express Runs
Express Runs
B A D C
A
B
C
D
B
A
D
C
Diagram A
600-ft. machine with traffic of 4 persons per 10 floors, 5-sec. stops.
Diagram B
Test at Hanover Bank building, 600 ft. speed, 1050-lb. load, 4-sec. stops.
Diagram C
500-ft. machine with traffic of 4 persons per 10 floors, 5-sec. stops.
Diagram D
Test at Trinity Building, 1600-lb. load, 500 ft. speed, 3-sec. stops

FIG. 4.

the writer indicate that the average passenger occupies for his or her entrance to the car at the starting point, exit therefrom, re-entrance, and final exit, a total period of 12 sec., and in addition, to every round trip, 9 sec. should be added to cover gate opening and start, at the top and bottom of the run.

The combination of time thus established covers the probable requirement of a landing to each passenger, and this is a duty which the machine must be prepared and proportioned to perform. It is not desirable to assume that any pre-determined proportion of passengers share a landing with others, since the capacity of the elevator must be such as will provide for the contingency of a separate landing for each.

The time thus established for passenger movement appears to be in very close agreement with actual conditions. Some trials in which the time occupied in stops or landings are given, together with the time of round trips, are plotted against the outline of a calculated or average trip in Fig. 4. One is that of the Hanover Bank elevators, already referred to, and the other, that of a plunger machine in the Trinity Building. It will be seen that the agreement of the actual with the computed conditions is very close.

A series of most interesting observations has been undertaken recently at the writer's suggestion, by Mr. Ernest M. Hill, on the traffic of the Ellicott Square Building, Buffalo, on August 21st, 1908. These observations are confirmatory of the assertions herein made as to the time occupied by passenger movement. This building is provided with two public entrances, at each of which are located two banks of Otis hydraulic-cylinder elevators, speeded to an average of about 350 ft. per min. Of these, five were in operation at the Main Street entrance, which is the busier of the two, and on these, a record was taken of every person carried either up or down, on every trip, of each elevator, during a period of ten hours, which averaged as follows:

Up, per car per trip	4.93
Down, per car per trip	4.53
Mean, per car per trip	4.7

The round-trip time of these five cars averaged 2.09 min., which closely agrees with a calculated time of 2.01 min. During the busiest

hour the traffic increased to 5.52 per trip, when the round-trip time lengthened out to 2.16 min. This is the same as the computed time based on the allowances of time, as herein stated, to each passenger.

These results, therefore, confirm the time allowance of 12 sec. to each passenger, and show that such a traffic reduced the speed between landings to 260 ft. per min.

The passenger elevator is thus seen to be an appliance in which, whatever be its designed functions, the time of its operation is subject to large modification by the passengers making use of it. It does not, therefore, stand in the same order as other machinery, but its operation is to be considered as in part that of the human beings carried, both as to numbers, as to their individual actions, and last and not least, in part that due to the idiosyncrasies of the operator.

Herein is to be found the reason for the wide variation in round-trip times, and in resulting convenience or its opposite, of machines of similar character and power, and much explanation may be derived of the difficulties under which designers of elevators have labored, in ascertaining the various elements which go to make up the speed capabilities of their apparatus.

The desideratum is evidently the attainment of maximum powers of acceleration and of retardation, and of the maintenance of traveling speed, with varying loads.

The ideal machine, for the attainment of maximum results, in traffic, will be that which will possess the power to attain with all loads, up to the desirable maximum, the designed speed in either direction, and in combination with a system of counterbalance related to its real average live load, will, with all loads, occupy the same distance for combined acceleration and retardation in either direction.

In the past, too great attention has been paid to the subject of operating economy, and that attention may now be profitably diverted to the more important question which determines the real work and economic value of the apparatus, namely, the amount of passenger traffic which the elevator shall be apportioned to convey.

DISCUSSION

Mr. Lavis. F. Lavis, M. Am. Soc. C. E.—It might be interesting if Mr. Bolton would state why it is necessary to operate elevators on a schedule. The service does not seem to be comparable to railroad service, because, carrying out the simile, each elevator has its own track and its own station, and apparently each could be run entirely independently of all the others. Mr. Bolton gave an illustration of a case where there was a battery of six elevators, one having a much smaller door than the others and, consequently, taking longer to load and unload. He stated that the round-trip time of this slow elevator controlled the round-trip time of the other five. It would almost seem that this one might have been operated independently and the other five run on their own schedule, if a schedule was required.

At times the speaker has occasion to visit the Park Row Building, where there is a large battery of elevators, and he has often noticed as many as three elevators on the ground floor at once, the waiting passengers being only allowed to enter one; when that was filled, those remaining might enter the second, and when that was filled, and started, the passengers still remaining might enter the third, by which time there were probably other cars waiting, and, at first sight, it would seem that time was being wasted, and that the cars might be started and make their round trip each as quickly as possible and independently of the others.

No doubt there are very good reasons for the operation of elevators in rotation and as nearly as possible on schedule time, and of course regularity, as a general principle, is generally conceded to be a good thing; but it is not always safe for engineers to figure on generalities, and the speaker believes some definite reasons for the necessity of schedule operation would be of interest.

Mr. Stanton. Robert Brewster Stanton, M. Am. Soc. C. E.—To most engineers who have not made the question a study, it is, perhaps, somewhat surprising that the general problems of railway transportation enter so extensively into "The Operation of Passenger Elevators." The author has stated that different classes of passengers—the fat man, the lean man, the man who rushes in or out before the gates are fairly open, and the man who never "steps lively," as well as the woman with the hat 3 ft. in diameter—all affect the successful operation of passenger elevators, especially in tall office buildings.

It may not be out of place to ask the author whether, in his calculations, the question of classification of passengers has been taken into account in order to determine its effect upon the successful, and as far as the tenants and patrons of such buildings are concerned, the economical, operation of such elevators. Railways classify, not only

their freight, but their passengers, though not, perhaps, on the lines above mentioned. The point to which it is desired to draw attention is this: In a large, centrally located building—one of the most expensive in the city—in which the speaker has had an office for the past six years, the employees of the building—scrubwomen with dirty, greasy buckets, bootblacks with large, besmeared boxes, and coal-heavers from the engine-room, with their clothes as black as soot—are allowed in every one of the ten passenger elevators of the building. This practice occasionally, in fact many times a day on some days, is a great inconvenience to the tenants and patrons of the building, as frequently they are obliged to wait for one or more trips before finding a car suitable for them to ride in to their offices. No objection is made to the employees—the men or the women—but, in rush hours, it is not pleasant to be squeezed in among the greasy buckets and blacking boxes, or against sooty jumpers, so that such practice, as with other things, hinders the regular and economical operation of the elevators. Mr. Stanton.

Some months ago, the owners of the building referred to requested their tenants to make suggestions as to its better management. In reply, the speaker wrote and suggested that one elevator of the ten be set apart for employees. An order to this effect was issued, and for a few weeks carried out, but it was soon neglected, and all elevators were and are used as before. This is not on account of the want of courtesy of the elevator or hall men, but is traceable directly to the Superintendent of the building, who, for some reason, refuses to carry out the orders of the owners. It would seem, therefore, that, in addition to those mentioned by the author, the disposition of the Superintendent is an item which should be taken into account as affecting, in the broad sense, the successful and economical operation of passenger elevators.

William J. Boucher, Assoc. M. Am. Soc. C. E.—One of the largest and highest buildings in New York City is equipped with electric elevators, all on local service. There are ten cars, five of which run to the 26th floor and five to the 25th floor. They are of a type which was installed quite frequently ten years ago, but which has since been largely superseded. The elevators are not giving satisfaction, and the entire equipment needs rebuilding. The management, however, is confronted by the fact that they have several important tenants whom they cannot afford to lose, as they would if there were a complete shut-down. Further, the machines are located so that it is impossible for men to work among them while the others are in operation. There is seldom a day when at least one car is not out of commission—perhaps one for a part and another for the remainder of the day. Due to the overloading, which is inevitable during the rush hours, the "safety" frequently springs on the "down"; this causes inconvenience to the passengers, who have to leave the cars by means of a step-ladder, and Mr. Boucher.

Mr. Boucher. the delay amounts to half an hour or more while inspection of the bearings and other parts is made. In the morning rush upward, the overloading is such that frequently several would-be passengers must leave the car before it can be started, and meanwhile the throngs are arriving and filling the hall, impatient to reach their offices.

The operation of cars on "schedule," or consecutively, is no doubt the best system, its greatest feature being that the hall man knows which car to expect next, and can direct the waiting people where to stand. Something has been said of the hall man and his efficiency. A great deal depends on these men; they can give good or poor service; and be it said to their credit, they generally do all in their power to make matters go smoothly. They are often hampered by the operators on the cars, who, whether by reason of insufficient pay or pure negligence, are frequently careless, and run the cars to suit themselves, by failing to stop for waiting passengers, this latter happening particularly at the top of the building.

The size or capacity of the cars has considerable to do with their efficiency, and one larger than its neighbors is a distinct drag on a system of elevators. The speaker learned to shun a car larger than its fellows, because it always started with so many passengers that their disembarkation delayed it so that it arrived at the upper floors later than the car which followed it from the ground floor.

A few years ago, a test of these elevators was conducted as a thesis test by students of Stevens Institute of Technology, and the following figures are taken from that test:

Offices per floor (various sizes)	39
Height, from ground to 26th floor	309 ft.
Distance between floors (generally)	12 "
Floor area of cars	36 to 44 sq. ft.
Average number of round trips per hour	16
Average number of passengers over entire trip	5.5

This last figure, however, is subject to great fluctuation, as cars frequently start with as many as fifteen passengers going up, and arrive at the top floor with one or two passengers. The tests showed:

Starting up, from ground, per hour	126 to 178 passengers.
Arriving at 26th floor	19 to 22 passengers.

Due to the peculiar system of roping these cars and counterweights, there is a great length of cable, and unless the operator is particularly skillful, there is a distinct and disagreeable "lurch" or "surge" at the stop, and many women passengers are made faint by the sensation.

Mention has been made of the newer electric installations, but it seems to the speaker as though the plunger hydraulic is giving the

most satisfactory service. Of course, there is some question as to the permanency of the installation tubes placed in the ground, and wet inside and outside, and it would be very interesting if Mr. Bolton would contribute from his knowledge the latest ideas on the subject. Mr. Boucher

Reginald Pelham Bolton, M. Am. Soc. C. E. (by letter).—Mr. Boucher has afforded a reply to the enquiry of Mr. Lavis as to the desirability of operating elevators on a schedule system, to which the writer would add the consideration that the consecutive method reduces the demand for power. Where schedules are not maintained, the loads of starting and of acceleration, and, in electric elevators, those of retardation, come together in excessive amounts. Mr. Bolton.

The main feature of schedule operation, however, is the convenience afforded on upper floors, by the accessibility of a car passing at regular intervals. To hold back each car until it is filled would, and does where practiced, produce a series of gaps of time when no car is available, while at other times, several cars are passing a floor simultaneously in the same direction.

The schedule interval, which is obtained by dividing the round-trip time by the number of cars, is a measure of the convenience of the service, and it has been found that where it exceeds 20 sec., in rapid business service, complaints soon arise.

The conditions referred to by Mr. Lavis seem to be those of the building, the elevator service of which is well described by Mr. Boucher, and those conditions are the result of an insufficiency of elevators as well as of speed. The result is that the surges of traffic delay certain cars, disorganizing the up-schedule and causing passengers to collect on upper floors, over-crowding the down-coming cars to the extent of over-speeding and causing at times the pawling of their safeties.

The figures given by Mr. Boucher show that these machines made on a trial only sixteen trips per hour, which corresponds with a round-trip time of 3.8 min. Under these conditions the traffic handled each way, on 25 floors, would be 140 persons per car per hour, with an interval or schedule of 23 sec.

The maintenance of this schedule, however, does not develop the capacity for which the machines are designed, as they should be capable of carrying 10 persons per trip each way. When this is done the round-trip time lengthens out to 4 min., and the schedule interval becomes about 24 sec. If these machines were replaced with such appliances as are installed in the Hanover Bank Building, the round-trip time would be reduced to 3.5 min., and the passenger capacity per car would be increased to 173 per hour, or a gain of nearly 24 per cent.

Mr. Boucher suggests that an elevator of the plunger-hydraulic type would effect better service, which is true to some extent, but the

Mr. Bolton. height of such a building involves a great length of plunger, carrying with it the accompanying masses of ropes and counterweights, making a combination sluggish in acceleration and retardation. The full running speed of such machines is not reached between stops, with the result that they give no more rapid service than other types of less speed. The short-run plunger machine has very desirable features, which disappear under long-run conditions.

The superior powers of rapid acceleration and retardation which have been developed in the "one-to-one" traction type of electric elevator, together with its capacity for maintaining traveling speed with maximum loads, place it in the front rank for schedule service, and with that apparatus the largest use can be made of the machine's share of the operating time. But even with these facilities, the result in the number of passengers carried and in the convenience of time afforded by the service, will be dependent mainly on the action of the passengers, operators, and starters, for which provision must be made by an ample number of elevators.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1109

THE BONDING OF NEW TO OLD CONCRETE.*

By E. P. Goodrich, M. Am. Soc. C. E.

With Discussion by Messrs. H. R. Burroughs, Theodore Belzner, James L. Davis, C. L. Slocum, Eugene W. Stern, E. J. Fort, Myron H. Lewis, W. C. Briggs, Frederick C. Harper, E. G. Walker, and E. P. Goodrich.

The necessity, in his general practice, of securing as perfect a bond as possible between masses of concrete which are deposited in abutting positions, but with longer or shorter intervals between the times of deposit, together with several demands for expert opinion as to the adequacy of the bond secured under certain given circumstances and with certain materials and methods, led the writer to make investigations into the history of the art, and to perform a series of experiments in the laboratory of the Polytechnic Institute of Brooklyn to determine how closely it is possible to approach a truly monolithic condition at such joints, when care is taken in executing the concreting in their vicinity.

Literature of the Subject.

The principal editorial in *The Engineering Record* of August 29th, 1908, discusses this subject with particular acumen. The remarks end with the statement:

"To sum up the whole matter in a phrase, the real obstacle militating against the bonding of fresh concrete to old, is dirt. This dirt may be an oily substance or a finely comminuted material forming an inert stratum constituting a most objectionable divided joint, or any

* Presented at the meeting of March 3d, 1909.

similar substance which prevents the new crystals of setting from attaching themselves continuously to those already existing. It is commonly supposed and stated as a general proposition that new concrete cannot be bonded to old. There may be room for legitimate difference of opinion as to the practicability of attaining that end. Any process not feasible of execution under ordinary conditions of work may be so difficult as to be practically impossible, but some engineers of experience believe that bonding new concrete to old will not long be classed in that category. If such a bond be attempted with a truly clean surface experience shows that intelligent manipulation involving some pressure will insure invariably successful results. It has many times been done on a small scale, and it is not too much to expect that under suitable conditions further experience intelligently directed may accomplish the same ends under ordinary circumstances. Efficiency of concrete work will be greatly enhanced in many cases if such an important end can be uniformly attained; and when it can be done on a small scale, ultimate success on the large scale of usual engineering works is not too much to expect."

The use of oil in some form, coated upon the forms so as to prevent the adhesion of any concrete to them, is a direct cause of much trouble when a good bond is desired between the old concrete and any further concrete, stucco, grout, etc. The primary reasons for the use of this oil are:

(*a*) To prolong the life of the forms (the alternate wetting and drying tending to rapid deterioration), although the natural life is not usually long enough to make this item of much importance.

(*b*) To lessen the labor incident to the removal of the forms.

(*c*) To lessen the breakage of the forms due to sticking while being removed.

The handling of oil about any parts of the work is likely to provide sufficient material to add to the natural difficulty of securing good bond at far distant points. Men carry it on their clothes, their shoes, and their hands, and, as it usually floats on water, a thin film is likely to rise to the top surfaces of fresh concrete everywhere and remain on top of the concrete when the excess water evaporates. There is seldom enough alkali in the cement to saponify completely such oil within any appreciable lapse of time, and, even when such saponification does take place, the soaps thus formed are sometimes not readily soluble in water, and there is practically never sufficient water used to dissolve and remove them, even when they are soluble.

For these reasons, the writer has lately made it a practice not to coat his forms, or else to use soap for the purpose; either hard or soft soap is suitable, and the only drawback to its use is its relatively higher cost. Its prime advantage is its solubility in clear cold water. When soap is used, it is necessary merely to flush the surface thoroughly with water to remove the otherwise troublesome film. In securing a bond, the excess water is useful for other reasons, as well.

Laitance is often responsible for imperfect bond. This point is discussed in the following remarks by L. J. Hotchkiss* on "Some Details of Concrete Construction":

"Occasions will arise, however, where a longitudinal joint in a wall is necessary, and where this is the case the thorough cleaning of the concrete is often neglected. The laitance is not all removed and dirt, shavings and sawdust are permitted to remain in the forms. This work cannot be left entirely to laborers but must have efficient supervision and inspection. The surface of the concrete should be scrubbed with wire brushes and water until every stone shows clearly, and the water used in the scrubbing should be flushed off and not left standing in the forms with the laitance in suspension, to be deposited on the concrete again as soon as the scrubbing gang has gone. Both time and expense can be saved if the cleaning is done before the concrete becomes hard. It can be done with shovels and a small amount of washing instead of the protracted scrubbing necessary later. The bond obtained in even the most carefully cleaned joint is of uncertain strength, and if the cleaning is poorly done, there is no bond at all."

Shrinkage cracks almost invariably reveal themselves in reinforced concrete floors along the joints between successive days' work. After a time, retaining and other walls of mass concrete very often reveal even the horizontal joints between successive deposits, and the writer knows of one such wall through which water has found its way to such an extent along such joints as to ruin the appearance of the face of the wall and actually cause anxiety as to its continued stability.

Taylor and Thompson† cite an instance "In the New York Subway", where:

"Work was commenced with no provision for bonding horizontal layers, but it was soon found that more or less seepage occurred, and in one case where a large arch was torn down the division line between two days' work was distinctly seen."

* *The Engineering Record*, March 9th, 1907.

† "Concrete, Plain and Reinforced," p. 376.

In demolishing old concrete work with wedges and sledges, an experienced workman always looks for the joints between successive layers, and the writer has often seen large masses separated by using only a crowbar when the old seam had been discovered. The commonly observed hollow sounds which issue from cement sidewalks and floors under traffic when the floors and walks have been constructed with special cement-finish coats are always due to a separation having taken place between them and the base course. This is obviously due to poor bond. After any considerable lapse of time, stucco, mortar, plaster, and grout which have been applied to mass concrete work, are oftener found to have separated than to have retained a perfect bond with the backing.

Gillette and Hill* call attention to one primary reason why proper bond is difficult to secure on horizontal and other much-worked concrete surfaces, where the mortar has been flushed to the surface:

"Concrete which has set hard has a surface skin or glaze to which fresh concrete will not adhere strongly unless special effort is made to perfect the bond. * * * The secret of securing a good bond between fresh concrete and concrete that has set lies largely in getting rid of the glaze skin and the slime and dust which forms on it."

In a paper on "Construction Details of Reinforced Concrete Work",† De Forest H. Dixon, Assoc. M. Am. Soc. C. E., says:

"The sloping off of concrete in the beams and girders should never be allowed. It is a well-known fact that there is almost no bond between old and new concrete."

and again:

"Granolithic finish should be placed monolithic with the slab, or, if placed afterwards, which is desirable in stables, and some other classes of work, its thickness should never be less than 1½ in. Recently, an acid solution has been placed on the market which the author has tried in several instances, using, in some cases, finish as thin as ½ in., put on concrete that had attained an age of several months. This finish has been in place for three months, and thus far shows a perfect bond."

The specifications prepared for large engineering works to be executed in concrete usually contain a short clause with regard to bonding old and new concrete, but they are very rarely at all explicit.

* "Concrete Construction, Methods and Costs."

† *Proceedings*, Municipal Engineers of the City of New York, 1907, p. 1.

the exact treatment usually being left to the resident engineer for determination. The following is the standard specification for work of this class, incorporated in all the published requirements for the several parts of the new Catskill Water Supply Development for New York City:

"For the proper bonding of new masonry to old, such provision shall be made of steps, dovetails, or other devices as may be prescribed. Whenever new masonry is joined to old, the surface of the old masonry shall be thoroughly cleaned, using stiff brushes and a stream of water; the laitance shall be scraped off and the surface shall be clean and wet at the moment the fresh concrete or mortar is placed. When ordered, a thick wash of rich mortar shall be brushed over the contact surface of the old concrete."

This specification is typical in the main, being rather better than most of the others in the writer's possession.

In the construction of tunnels, and heavy or extensive work of all similar kinds, joints are inevitable, and the designer must study each case carefully and devise proper quantities and arrangements for the reinforcement which is essential to securing the work against the appearance of shrinkage and temperature cracks along such natural joints. The subjects of setting shrinkage, and change of size from fluctuations of temperature and humidity, are intimately connected with the subject of bonding old and new concrete, but will not be discussed here, although they have all been investigated, both experimentally and analytically, by the writer in this and closely related work.

Another and a very vital and closely related question, and one which exists in the minds of most constructors, is as to the proper place in reinforced concrete floor-beam constructions at which to leave the joint between successive days' work. In the last analysis, if a perfect bond could be secured between the successively deposited masses, it would not matter in the least how or where one day's work were stopped. Usually, a compromise has been deemed best, and the joint made at about the quarter point in the span of a beam or slab, where neither the bending moment nor the shear is a maximum.

Patented Processes.

All the treatises on concrete discuss this important subject of bonding, but tell very little of real value. Ernest L. Ransome, Assoc.

Am. Soc. C. E., has secured several patents on the general treatment of concrete surfaces, with mechanical bonding devices and with acids, to secure a better connection; and other methods have been devised which make use of bituminous and other compounds to be applied to the old work and in preparing the new mortar. These are mostly used where it is the intention to apply stucco or plaster to mass concrete. Usually, these compounds are also claimed as resisters of dampness as well as bonding agents. Only one such process, not primarily for damp-resisting purpose, is known to the writer. In it a special preparation of coal-tar is used in the place of water in mixing the mortar for the new floor or sidewalk wearing surface.

The first patent (No. 647 904), issued to Mr. Ransome, concerning the subject of bonding, was dated 1898, and covers a "concrete joint strengthened with a metallic coil embedded in both of the joined masses."

Patent No. 694 578, also issued to Mr. Ransome, covers:

"The method of forming a bond between two bodies of concrete, which consists in first sprinkling over the surface of the first made body of concrete while yet soft and unset, a layer of prepared honeycomb slag, embedding the same into the surface, allowing the concrete to set and after removing all superfluous slag, covering it and embedding its exposed surfaces with the second body of concrete."

Patent No. 767 582, issued to Mr. H. L. Lewman, is

"In a concrete construction, adjacent sections connected by a bendable tie-piece having looped portions embedded in each section with its free ends meeting at its mid-length, and a connecting strip extending between said looped portions of the tie-pieces and having its free ends bent to intersect the body thereof, or with a rod extending through the opposite loops of each tie-piece at an angle thereto."

The best known of these patents is No. 800 942, issued to Mr. E. L. Ransome in 1905. It has to do with:

"The improvement in the art of forming structures of concrete and the like, which consists of forming a layer of plastic material containing cement, and permitting the same to harden, in removing portions of the hardened surface of said layer by the application of an acid thereto, in removing from said surface by washing the excess of acid and resultant salts and disintegrated material, and in forming a second layer of plastic material containing cement, over said surface of the first layer, and permitting the second layer to harden, whereby to form a perfect bond between the two layers."

In a pamphlet describing the use of a special mortar for cement floors, stucco, etc., Albert Moyer, Assoc. Am. Soc. C. E., gives the following method of securing proper adhesion between old and new cement in cement floor work:

"Sweep off the concrete surface thoroughly with a broom, wash the surface with clear water and sweep off with a broom. As soon as the excess water has been taken up by the atmosphere or absorbed in the concrete, paint the surface with a solution of one part commercial muriatic acid, three parts water; paint on three coats one right after the other. Within a few minutes wash off the surface with clear water, sweeping with a stiff broom. This removes all particles of dead cement which may remain on the surface, exposing each grain of sand and other aggregates which compose the concrete in very much the same condition as they were before being mixed. This also wets the concrete quite thoroughly.

"While the concrete is still wet, place an inch coat of mortar * * * ."

The removal of efflorescence from concrete work, by the application of an acid wash, is so similar in method and result to that required in obtaining a perfect bond that the following description* may well be included for the sake of completeness:

Commercial hydrochloric [muriatic] acid, diluted with from 4 to 5 parts of water, was applied, and the surface scrubbed with common floor scrub brushes, water from a small hose being constantly played on the concrete while the cleaning progressed, so as to prevent the penetration of the acid. The cost on straight work was estimated at about 2 cents per sq. ft. cleaned. An experienced stone renovator should be employed whenever possible. Hydrochloric, acetic, and oxalic acids were experimented with, in conjunction with the scrubbing. All were effective. Hydrochloric acid was the best, requiring less scrubbing. Acetic acid came next in efficiency.

In this case the endeavor was simply to remove the thinnest possible layer from the surface, the acid being prevented from penetrating to any appreciable extent. In the patented process for securing decorative surface results on concrete by etching with acid, covered by letters patent No. 716 371 granted to Block and Richards, December 23d, 1902, the method is closely analogous to that necessary to secure a good bond, and is described as follows:

"The process of producing a natural finish on artificial stone composed of cement and particles of natural stone by subjecting it when

* Abstracted from *Engineering News*, October 31st, 1901.

molded and dried to a solution of muriatic acid, then rinsing the same in water, then subjecting the same to a solution of carbonate of soda, and finally rinsing the same in water."

Published Experiments.

Few experiments have thus far been published with regard to methods of bonding masses of concrete, but in *Engineering News* of August 13th, 1908, is given an abstract of a graduation thesis prepared by Raymond B. Perry, of Case School of Applied Science. He prepared and tested by flexure small concrete-beam specimens, $2\frac{3}{4}$ in. square and $27\frac{3}{4}$ in. long, which had been spliced at their centers. A variety of methods of splicing were used, none of which developed the strength of an unspliced specimen. His results and deductions are repeated here for future reference and comparison.

TABLE 1.—Perry's Tests.

Condition of Joint Surface.	Roughened.	Smooth.	Rough.	Smooth.	Moulded Groove.	No Joint.
Treatment.	Wet.	Grouted.	Grouted.	Ransomite.		
Results of tests, in pounds per square inch	158	119	279	232	173	255
	123	131	211	128	133	230
	87	207	237	220	120	249
	124	82	225	231	128	271
	128	124	227	146	110	257
Averages, in pounds per square inch...	124	133	236	191	133	252

"While experiments of so limited character are not absolute in their results, it may be concluded with some degree of certainty:

"(1) That the bond existing between new mortar or concrete and old, where the old surface is smooth, is very slight.

"(2) That about one-half of the strength of the concrete is developed in a joint bonded (*a*) by roughening the old surface; (*b*) by applying a layer of cement paste; (*c*) by providing the old surface with a bonding groove.

"(3) That a large part of the strength of the concrete, perhaps as much as 90%, is developed where the old surface is roughened and a layer of cement paste is applied.

"(4) That such a solution as 'Ransomite' practically takes the place of the roughening, since a bond made with it is otherwise similar to the one made in these tests by roughening the old surface and applying a layer of cement paste."

"Ransomite" is a powder which is to be dissolved in water in order to obtain the bonding solution.

These tests closely followed some experiments described in *Annales des Ponts et Chaussées,* Pt. 3, Vol. 27, 1907, the results of which were summarized as follows in *Engineering News* of December 12th, 1907:

"A [neat] cement joint is an aid in connecting old concrete work to new, and * * * whether this joint is used or not, an excessive tamping of the new work near the joint will add appreciably to the strength of the connection."

TABLE 2.—FRENCH TESTS.

SPLICED AFTER:	7 DAYS.		30 DAYS.	
Treatment of joint.	No grout.	Grouted.	No grout.	Grouted.
Results of tests, in pounds per square inch	24 97 67	209 175 300	171 154 142	159 302 227
Average, in pounds per square inch.....	63	223	156	229

It is stated that of the above splices, those made after 30 days, were better tamped than the earlier ones. It is also to be noted that the mechanical arrangements of the test brought a considerable direct compressive stress upon each joint, and in consequence these tests are not strictly comparable with any others.

The specimens were of the same size and kind as those made by Perry, and all are open to the objection of revealing results comparable only with one another, as there is at best only an approximate relation between the maximum stresses developed in bending and those produced under direct stress.

Professor Mörsch* gives the following results, showing that the direct stress may be considered to be about one-half that developed in bending when computed according to the usual formula. The stresses are in kilograms per square centimeter.

TABLE 3.—MÖRSCH'S TESTS.

Mixture.	1 : 3		1 : 4		1 : 7	
Percentage of water.....	8	12	8	14	8	14
Bending stress.....	21.4	23.2	16.1	16.7	13.3	12.8
Direct tension.....	12.6	10.5	9.2	8.8	4.4	5.5

* "Eisenbetonbau," pp. 35–36.

The writer is not aware of any experiments having been made with regard to the bonding qualities of stucco or cement finish for concrete floors or sidewalks, except a single test with brick as a backing, made by Professor Ira H. Woolson, at Columbia University, for the exploiters of a special water-proofing cement mortar. His report reads in part as follows:

"Description of Specimens.—Two specimens were submitted for test, and each consisted of a common red building brick, with a coating on one side of about one-half inch of the cement. The cement was thoroughly dry and hard.

"Object of the Test.—The object of the test was to ascertain what degree of heat the cement would sustain without injury, either by cracking or by disintegration.

"Method of Test.—In order to develop the full effect of possible differences in coefficients of expansion due to heat in the two materials, the specimens were heated on the cement side only, and the brick kept cool as it would naturally be in a wall, where the face of the wall was heated. To accomplish this object, the specimens were laid, one at a time, horizontally before a side opening in a small gas blast furnace. To insure that the heat was uniformly distributed over the whole face of the cement, a $\frac{3}{16}$-inch sheet of composition asbestos board was used to close the furnace opening, and the cement face was placed near to it, but not touching.

"In this narrow air space between the cement and board the thermo-couple of a Le Châtelier electrical pyrometer was placed, by which the temperature of the face of the cement would be accurately and continuously recorded.

"The heat was raised gradually and temperature read every three minutes. The total time of heating the first specimen was forty-five minutes, and the temperature attained was 1 000 degrees, F. At the time no cracks or other defects were noticeable in the cement, and the brick was cool enough to allow its being easily removed from the furnace by the bare hand. However, in a few minutes after removal, a crack developed along the line of juncture, between the cement and brick, which gradually spread until it had separated about half of the cement from the brick.

"The cement adhered to the brick so firmly that the crack in places ran into the body of the brick itself. No other disintegration occurred.

"The second specimen was heated the same way, but the time of heating was reduced to fourteen minutes, and the temperature to 600 degrees, F.

"This specimen showed no effect whatever due to the heat either hot, or later when it had fully cooled.

"It is quite evident that the cracking of the first specimen was due to unequal expansion of the brick and cement, and rapid cooling. It is possible that the cracking might not have occurred if the specimen had cooled slowly."

While the engineering periodicals have published quite a number of communications from time to time with regard to the proper points in concrete floor construction at which to stop work, still these discussions have all been of an entirely academic nature, no experiments having been made with regard to this fact, so far as known to the writer, except in the case of the reinforced concrete reservoirs for Mexico City, described by James D. Schuyler, M. Am. Soc. C. E.*

There are four reservoirs, all circular in form, and 105 m. in diameter at the top. The roof consists of a 6-in. slab of reinforced concrete supported by radial and concentric beams, resting on cylindrical pillars of concrete, all properly reinforced.

"In the building of such a massive roof over so large an area as each of these reservoirs presents, the question of sustaining the forms during the time required for the setting of the concrete was one of the most serious problems to be solved. To build up timber supports of requisite stiffness and stability reaching from the floor to the roof, on account of the height, would have required a vast forest of timber, of little subsequent utility, and costly to erect and remove. It was finally determined to suspend the forms from the tops of the columns by a series of steel I-beams of standard sizes and lengths which would have a market value for building construction of at least 75 per cent. of their cost after the works were completed. But in order to place the top series of I-beams high enough to act as suspensors for the forms of the main reinforced concrete beams, it was necessary to build up the capitals of the columns to the ultimate height of the top of the roof as bases on which to rest the temporary hanger beams, and in these concrete capitals, which form the ends of four intersecting concrete beams, mold all the steel reinforcing rods subsequently required for the concrete beams. This in effect meant the formation of the ends of the beams a long time prior to their ultimate completion. Hence to determine the effect of this composite construction of a beam, with a joint near each end, upon the final strength of the beam, a series of tests were made in the Condesa testing laboratory, with four full-size beams reinforced as they are to be used in the roof of the reservoir. Two sets of tests were made, with two beams each, 14 and 28 days after molding. These beams were 14 ft. 9 in. long, 19⅝ in. deep, 7¼ in. wide, with a clear span of 13 ft. 1 in. between supports. In

* *The Engineering Record*, March 28th, 1908.

one beam of each set, the two ends were molded two days in advance of the remainder, in the form shown by the shaded areas of the diagram, leaving a well-defined line of jointure between the concrete of the ends and the central portion of the beam.

"Test A, at 14 days, was made under the following conditions: The solid beam had been molded complete at one operation, with 1:2:3 concrete, reinforced at bottom with two square corrugated bars ½ in. by 14 ft. 10 in.; two diagonals ½ in. by 15 ft. 6 in.; three oblique bars ½ in. by 5 ft. 2 in. at each end, and diagonals, from center to ends, ½ in. by 7 ft. 6 in., the metal in all being 0.7 per cent. of the beam. With 3 809 kilos applied at two points at one-half meter from central axis, the deflection was 2.4 mm.; with 6 185 kilos applied load, the deflection was 4.6 mm.; with 10 369 kilos the deflection was 8.2 mm., when three cracks appeared, half the depth of the beam, at distances of 1.5, 2.9 and 3 meters from one end. The final rupture occurred under a weight of 11 460 kilos.

"The second beam of the pair, molded in sections as described, showed a deflection of 2.4 mm. under 3 908 kilos, 4.8 mm. under 6 815 kilos and 8.0 mm. under 10 369 kilos, when four cracks appeared, 20 cm. long, at distances of 1.5, 1.7, 3.0 and 3.1 meters from one end, all inclining toward the load. The final rupture took place with a deflection of 20 mm. under a load of 13 648 kilos without the slightest sign of weakness appearing at the joints in the concrete. * * *

"Test B, at 28 days, gave results quite in parallel with those of Test A. The mixture was the same, but the reinforcing metal was greater, amounting to 1.0 per cent. of the beam, consisting of three straight base bars in bottom, two of which were ½ in. square and one ⅝ in. square, 14 ft. 10 in. long; also two base bars with diagonal to top at ends, each ½ in. square and 15 ft. 6 in. long; three intermediate top and diagonal bars at each end, each ½ in. square and 5 ft. 2 in. long and two central diagonal and top bars, each ½ in. square and 7 ft. 6 in. long.

"The beams showed the following comparative results during test:

"Applied Load. Kilos.	Solid Beam. Deflection.	Beam Molded in Sections. Deflection.
3,809	2.0 mm.	1.8 mm.
6,815	3.0 mm.	3.2 mm.
10,369	7.0 mm.	5.6 mm.
12,556	10.0 mm.	7.2 mm.
14,742	13.0 mm.	8.8 mm.
16,929	22.0 mm.	10.2 mm.
10,018	Ruptured by compression.	
19,116	.....	12.4 mm.
21,299	.....	16.4 mm.
22,390	.....	Ruptured by compression.

"In each beam, cracks began to appear under a load of 10 369 kilos. * * *

"In this case, also, the absence of any cracks or sign of weakness on the line of joints between the older and newer portion of the concrete beam seemed to prove conclusively that there was no weakness to be feared from this fragmentary method of molding as compared with the monolithic beams, but, on the contrary, they developed greater strength in each case."

The Writer's Experiments.

It did not seem necessary to experiment as to the necessity of a thorough cleaning of the old concrete surfaces. This requirement is so obvious that it is surprising to note the way many constructors apparently ignore it. A number of years ago, the writer discovered the advantages of using a jet of steam for this purpose, and in *The Engineering Record* of March 7th, 1907, he advocated its use, and gave several other hints on concrete work. The only other engineer who has advocated it is Mr. Ernest McCullough, who writes as follows:*

"Nothing is so absolutely bad for joints as sawdust and nothing is so hard to get rid of. Shavings and blocks of wood are picked up with rag pickers' sticks, which are pieces of wood about one inch square having a sharpened nail driven into one end. Loose gravel, etc., can often be brushed out. Sawdust however remains. Even a strong stream of water fails to get rid of it. Live steam at a high pressure will however clean off the surface of the concrete to the bone. It removes all the half-set and dead cement and all the sawdust.

The writer's experiments were of three varieties, and were arranged with the following objects in view:

(*a*) Measurement of actual tensile strength with five methods of bonding, applied to two varieties of surfaces, and after two different time intervals;

(*b*) Determination of the qualitative effect of exaggerated temperature changes on samples representing cement floor or sidewalk finish, placed after a relatively long lapse of time, with the help of acid treatment, as compared with simultaneous placing of the bottom and top layers;

(*c*) Determination of the advisability of depositing concrete for a deep beam in separate layers with intervening time intervals;

(*d*) Determination of the best point at which to splice concrete floor members between successive days' work;

* "Reinforced Concrete," p. 108.

(*e*) Value of acid treatment in ordinary floor and walk work.

The tension tests were made on standard cement briquettes. Only 1:2 (by weight) Portland cement mortar was tested.

All specimens were cured in air only, to be more nearly analogous to practical working conditions. Splices were made after intervals of 24 hours and of 7 days. All specimens were broken at the end of 30 days. For the sake of comparison, unspliced specimens were moulded and broken after the same period. One series of briquettes was made and broken after 24 hours. The half briquettes thus obtained were utilized in one series of experiments, half of them being spliced after a lapse of 24 hours and the other half after 7 days. It was considered that this series would represent conditions when the surface of old work was entirely broken away and all loose material removed just before the new material was deposited. Another series of briquettes was moulded with a thin strip inserted at the smallest section. When removed from the moulds, of course, these briquettes fell apart into two pieces, the surface next the partition having the exact appearance of having been moulded against a common wooden form. After 24 hours, and 7 days, these half briquettes were spliced, the surfaces to be bonded first being indented with a sharp steel tool in just such a form as would be given with a pickaxe or blunt chisel, according to the usual methods of roughening surfaces to be joined. Five methods were used in making bonds, or rather in connection with the making of the bond:

(*a*) The soft mortar was moulded against the half briquette with only as much manipulation as is usual in depositing concrete work. The old half was used dry in its natural state.

(*b*) The old half briquettes were first soaked in water for about 10 min. and then the new end was moulded as in (*a*).

(*c*) A creamy mixture of neat cement was prepared, and the ends of the half briquettes were dipped in it. This formed a coating similar to that most often specified and used. The new ends were then moulded in the usual way, before the grout had set to any great extent.

(*d*) The ends of the old briquettes were liberally washed with a 1:10 solution of commercial hydrochloric acid. They were then washed in clear water to remove all unspent acid, and the new ends were moulded as usual.

(*e*) A solution of "Bondsit" (a powder similar in nature to "Ransomite") was prepared in accordance with the directions sent with the can, or at the rate of 5 lb. of the powder to 10 gal. of water. This solution was then used in the same manner as in (*d*).

Three specimens representing each age, type of surface, and method of bonding were prepared.

Mortar specimens were decided upon, because it was believed that it is the mortar which has been flushed to the surface and against the forms on each side of the joint, which is the real bonding medium.

Briquettes were used for several reasons:

(*a*) Measurements of the true tensile strength of the bond could be most easily obtained.

(*b*) With the small size of the specimen it was thought that one would be more likely to obtain more uniform results than with specimens of larger size.

(*c*) If good results could be obtained with small specimens, a standard would be provided to be applied over larger areas.

There may be some question as to the truth of Assumption (*b*), because, over larger areas, local deficiencies would be merged with strong sections, so that a somewhat smaller variation would probably be obtained. The actual wide variation, in some cases, is instructive as to the probable conditions at different points in any joint. The narrower range found with some methods of bonding demonstrates, if anything at all, that it is possible with them to gain a better distribution of stress over larger areas than with the other methods.

The powder when put into solution gave a white precipitate when tested with barium chloride, showing that the acid in this case is sulphuric.

The results obtained from the tension bonding tests are contained in Table 4.

While the results in Table 4 are not as concordant as might be wished, still certain deductions may safely be made:

(*a*) The best results were obtained with surfaces having the roughness produced by the natural fracture. This points toward a purely mechanical bond, or one with little cementitious action.

(*b*) Practically no bond was obtained on surfaces which were moulded against forms and had dried for 7 days. This is shown by the large percentage prematurely broken, even with careful handling,

and the relatively low results obtained at best. Thorough soaking of the old work is essential.

TABLE 4.—Goodrich Bonding Tests.

	Rough Surface.				Smooth Surface.			
	24 Hours.		7 Days.		24 Hours.		7 Days.	
	Each.	Average.	Each.	Average.	Each.	Average.	Each.	Average.
Plain.....	161 *C* 92	126	285 313 343	314	162 205 80	149	*C* *H* 15	15
Soaked....	*H* *H* 60	60	138 218 212	189	165 90 208	154	*H* *C* 44	44
Grouted...	380 315 *C*	347	347 280 200	276	98 43 160	100	*H* *H* *H*	.....
HCl	68 *C* 155	112	126 175 221	174	87 232 105	141	83 51 44	53
"Bondsit".	30 60 *H*	45	152 105 95	117	79 54 68	67	172 26 114	104
Average...	147	.....	207	.....	122	.....	69	.....

Whole Briquettes.
363
384
309
438
415
304
427
Av. 377

H = Broken while handling before expiration of 30 days.
C = Broke in testing machine while adjusting clips.

(*c*) It was noted with regard to the 7-day, smooth surface, grouted bond, that the water was absorbed so rapidly from the grout as to render it an actual detriment. However, the results obtained with regard to the 24-hour and 7-day, rough surface, soaked, specimens might lead one to infer that there is a possibility of using too much water. This latter may be the case in laboratory work, but, in the writer's building experience, few laborers have ever been met who were prone to use water to what seemed an excess. In applying stucco work, or lining reservoirs, however, an expert workman knows that there is a real possibility of too completely saturating the old work, and it requires long experience and great care to obtain exactly the proper humidity.

The use of dry cement sprinkled over old concrete surfaces which have first been dampened is of questionable value, in view of the writer's experience.

(*d*) A coating of grout is advantageous, first having soaked the old concrete thoroughly to prevent the water in the grout from being absorbed too rapidly.

(*e*) Acid treatment at an age of 24 hours is not of appreciable value.

(*f*) On surfaces originally moulded against forms, after having dried for 7 days, acid is advantageous.

(*g*) Results with the use of acid were more consistent among themselves than with any other method.

(*h*) Why the splices made after the 7-day interval are so much better than those made after 24 hours on the rough surfaces, is difficult to explain, unless it be that the breaking to obtain this rough surface had loosened many small particles which still clung to the damp surface while only 24 hours old, but which were naturally removed during the handling incident to the 7-day tests.

(*i*) The bonds secured on rough and smooth surfaces after 24-hour intervals are not materially different.

While the acid treatment does not give a bond as strong as when the old surface is rough-pointed, still its cost is much less, and where an absolutely monolithic condition is not essential, but where fairly good bond is required, the use of acid is of value.

Again, where proper reinforcement is provided across joints, the use of acid is advisable and sufficient.

The powdered material is much more convenient to handle than the commercial acids shipped in glass carboys.

In view of the writer's and the other bonding experiments quoted, the following may be given as a proper mode of procedure:

"For connections made after a lapse of 24 hours or more, break back the surface concrete to firm material, and clean the fresh surface with steam, air blast or forceful water streams so as to remove all fine loose material. Saturate well, but not so that water stands on the surface or oozes from the material. Paint completely with neat cement grout, mixed to the consistency of thin cream, just before new concrete is deposited, and see that the latter is of proper mixture, containing a proper proportion of mortar, which should be worked against the joint so as to be certain that no voids exist in its vicinity.

"For connections made after long intervals, so that the old cement has set hard, and where the expense of rough-pointing the whole surface is greater than is required because of the nature of the desired bond, use commercial muriatic acid, diluted with clear water, 1 to 5, or the commercial bonding powders, dissolved in clear water at the rate of 5 lb. of powder to 10 gal. of water. First wet the old concrete surface with so much water that a fresh wetting is not immediately absorbed. Remove any excess of moisture and, when the surface appears as if commencing to dry, paint on the old surface three successive coats of acid one after the other. Let this remain for about 30 min., after which carefully clean the surface of unspent acid, soluble salts, and fine material, with plenty of water, finally cleaning with a steam jet or air blast if obtainable. Just before the fresh concrete is to be deposited, and while the old material is still very damp, apply a thin coat of neat cement grout mixed to the consistency of thin cream, just before the new concrete is deposited, and see that the latter is of proper mixture containing a proper proportion of mortar, which should be worked against the joint so as to be certain no voids exist in its vicinity."

A block representing a small section of a concrete sidewalk, or floor, was also prepared. It was just of a size to fit a furnace door under a high-pressure steam boiler. The concrete base was moulded 3 in. thick, in two operations, each covering half the area of the block. Reinforcing rods were left protruding from the first part deposited, so as to cement it firmly to the second one. The latter was placed 7 days after the first one. The surface of the latter was prepared to receive the finish coat by applying a solution of "Bonsit," according to the specification previously given. As soon as the concrete of the second section had partially set a ½-in. coat of 1:3 cement mortar was spread over the whole area of the block and well troweled so as to secure as good a bond with the backing as possible. The whole was allowed to set for 30 days, and was then subjected to an alternate heating and cooling by being placed first in the furnace door for a few minutes and then allowed to cool in the outdoor air. These alternate periods of heating and cooling were as follows:

Heated 12 min.	Heated 7 min.
Cooled 13 "	Cooled 15 "
Heated 15 "	Heated 5 "
Cooled 35 "	Cooled 15 "
Heated 5 "	Heated 10 "
Cooled 13 "	Cooled.

The temperature on the mortar face (the one toward the fire) was allowed to rise until steam was seen to issue from the edge of the block between the mortar and the concrete. The temperature at the depth of the joint was then approximately 200° Fahr. The exposed face was much higher, while what would be the bottom of the floor or sidewalk was not more than 60° Fahr. when tested by the hand. The block was then removed from the fire and allowed to cool until the hand could rest comfortably upon what had been the exposed face. This would correspond to a temperature of about 120° Fahr. The heating operation was again repeated, the time of exposure again reaching a point when steam appeared. After the second heating, the back of the block reached a temperature which was just a little too hot for the hand. At each cooling this fell to about 120° Fahr., but at the same time the mortar face must have had a range of temperature of at least 100 degrees.

After the second heating, a minute examination of the edges disclosed a hair crack along the joint between the two layers of the oldest and the newest materials; when the block had cooled so that it was about ready for another heating, a fine crack was also observed across the top along the line between the two parts of the backing. Evidently, a separation would have taken place except for the reinforcing bars. This crack could not be found on the bottom of the block, and it closed up entirely during each heating, appearing again during each successive cooling.

After the third heating, a narrow strip around two edges sounded hollow when tapped with a hammer. After each successive heating and cooling, this hollow area increased somewhat, until, after the fifth heating, it included about half the area over the older section. After the final heating, however, when a hammer was used to break away the loosened surface coat, not more than two-thirds could be thus loosened, some parts carrying off adjacent portions of the backing. That portion in which the top and bottom were placed at the same time could not be separated with a clear plane of cleavage, even after the specimen was broken into fragments. In the latter condition the two parts of the other half of the block readily parted under a smart blow. However, from the writer's experience, and from a study of the conditions of the test at the site during its progress, it can be positively affirmed that the value of the acid treatment was demonstrated by the adhesion still remaining even after the repeated heat applications.

No physical or weather conditions are ever as severe as those provided in connection with the furnace, and, even if each heating and cooling might be likened to an annual experience, ample bond remained after five summers and winters to warrant a contractor's guaranty, if the whole bonding operation were faithfully executed. Under actual weather conditions, the changes of temperature are not nearly as sudden or widely varying, so that the effects of the slightly different coefficients of expansion are very small.

On the basis of coefficients of 0.00000655 and 0.00000795 for mortar and concrete, as given by Bonniceau in *Annales des Ponts et Chaussées,* and with a temperature difference of 100° Fahr., there would be a difference in length of only 0.00000140 for each degree, or 0.000140, so that in blocks 100 in. square, in which the maximum probable action would not be more than 50 in., the difference would be only 0.007 in. On the assumption of a modulus of elasticity of 2 500 000, the resulting tensile or compressive stress (ignoring any reduction in amount due to resulting strains) would be only 3½ lb. per sq. in. if uniformly distributed, or at that rate if concentrated at any one or more points. Whenever the bond becomes broken it must therefore be concluded that it was not sufficiently strong to withstand a shearing stress between the top and bottom layers of the amount thus computed. When it is recalled that such shearing stresses should be much more than equal to corresponding tensile ones, the inadequacy of much work is apparent, and the tests of the tensile strengths developed by the various methods of securing a proper bond tend to prove that a sufficient bond can be secured in floor and sidewalk work with proper workmanship, particularly if some special method like the acid treatment is used, in the very execution of which a sufficient number of special precautions are added to improve the result perceptibly.

The final experiment consisted in the fabrication of a reinforced concrete beam, doing the concreting in sections, each succeeding part being deposited after a lapse of about a week from the last one, while the beam was tested after a final lapse of only two weeks after the last section was concreted. The several parts and the order of deposit were as shown in Fig. 1. The mixture used was 1:2:4 (by weight), the broken stone being the run of the crusher, up to ¾-in. One of the bonding powders (Bonsit) was used to better the connection between successive parts. The beam was tested, on a 6-ft. span, with a center

load, the first application, up to 2 500 lb., being applied at the neutral axis on two projecting rods which were cast in the beam for the purpose. The concrete section was 8 by 4 in. over all, reinforced with two ½-in. smooth round rods placed ½ in. above the bottom of the beam, each one extending from one end to a point about 1 ft. from the other point of support. Each end was bent upward in a comparatively

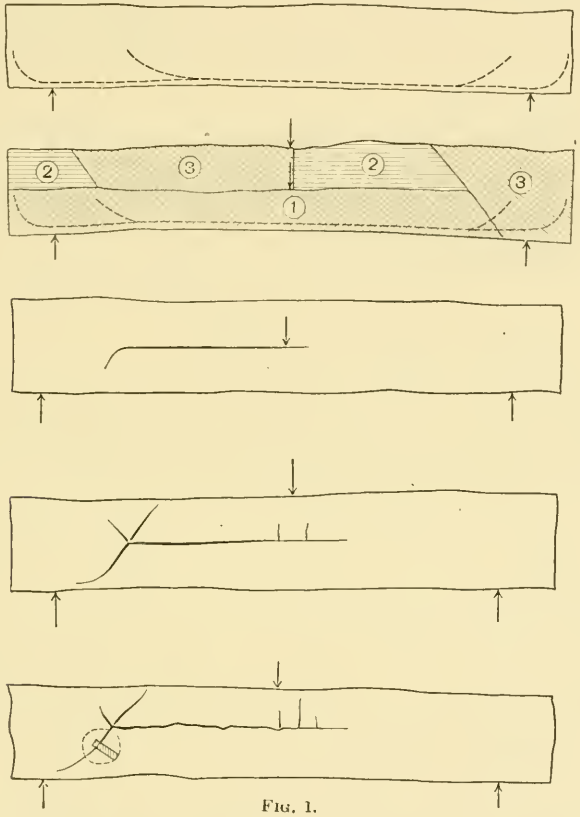


Fig. 1.

large-radius turn, the one at the end through an angle of 90° and the other one through about 45°, so as to serve to some extent in resisting diagonal tensile stresses. The reinforcement aggregated 1.34% of the effective beam area. The beam weighed about 180 lb. The load was applied in increments of 500 lb. each, the effect of each being carefully noted.

The shapes of the sections were determined with the following objects in view:

(*a*) To determine the effect of a horizontal joint in a beam, even when bonded as well as possible, where no steel is used for the purpose, when the load is applied at the level of the joint. This is the condition which exists in beams which are designed to be as deep as the distance between vertically adjacent window heads and sills in a concrete building, and where the concrete is almost invariably deposited in two separate operations, with the joint between them occurring at the level of the concrete floor.

(*b*) To ascertain whether it were possible to secure, along surfaces theoretically close to those on which maximum diagonal tensile stresses are developed, a bond of sufficient strength to make it unobjectionable to stop work along such a surface.

(*c*) To ascertain whether there is any virtue in leaving a joint only along a surface theoretically close to those on which maximum diagonal compressive stresses are developed.

The test results obtained were as follows:

(*a*) At 2 500 lb., applied at the center, a horizontal crack appeared, extending from the load toward one end and turning sharply downward into the mass concrete close to the turned-up end of one rod.

(*b*) The load was then shifted to the top of the beam, whereupon the horizontal crack disappeared entirely and the diagonal one was barely visible.

(*c*) At 1 500 lb. applied on the top, a condition almost identical with (*a*) had been reached.

(*d*) At 3 500 lb., the diagonal crack had extended downward and was following along the reinforcing rod toward the end of the beam. Very small tension cracks had appeared in the upper part of the beam under the load, and a wedge-shaped piece was commencing to crack out at a point where the diagonal and horizontal cracks intersected, in the vicinity of, but not along, an artificial joint parallel with diagonal compression planes.

(*e*) The load gradually fell to about 3 000 lb., as more strain was produced, and all these cracks became more prominent, until a sliver of concrete was forced off, revealing the end of one rod cutting directly across the main diagonal crack.

The rod had slipped in the concrete near the end of the beam, but adhered firmly to that on the other side of the crack.

It is to be noted that the artificial joint, where diagonal failure was expected to occur, was closer to one point of support than was the crack which actually occurred at the other end. Thus the diagonal stresses were larger on the artificial joint than they were where the mass concrete failed.

The results obtained in this particular beam may be summarized as follows:

(*a*) In a beam, a horizontal joint not reinforced with steel, even if carefully bonded with acid and grout, is such a cause of weakness that the beam should be designed of a height only up to the joint, whenever the load is applied at the level of this joint.

(*b*) In a beam, a joint can be made sloping in the direction of the cracks caused by diagonal tensile stresses, which will be as strong as mass work, if the joint is bonded in accordance with the specifications given above.

(*c*) In a beam, the concrete in the vicinity of a diagonal joint parallel with the lines of maximum diagonal compressive stresses will fail before a joint made oppositely does, if incipient failure has already occurred in the vicinity of what may be called the compression joint and has not done so near the tension joint.

As a general conclusion, it may then be stated, that if proper bonding methods are adopted, with acid and grout, work may be stopped along 45° planes at any point in a beam, at pleasure, between the ends and the third points. In view of the one other test reported besides the writer's, such planes would better be diagonal compression planes. The writer prefers such joints to vertical ones at the centers of beams, where direct tensile and compressive stresses are larger. Further, it is to be remarked that nothing but ample reinforcement, consisting of stirrups or numerous diagonal rods, can compensate for the detrimental effect of a horizontal joint left along or near the central axis of a beam. The writer prefers numerous stirrups, well connected to the tension rods, and amply anchored in the top concrete. In proof of the efficacy of this design, reference may be made to his brick beam experiment, and the one in which no concrete at all was placed around the tension rods.*

* *Transactions*, Am. Soc. C. E., Vol. LVI, p. 343.

DISCUSSION

Mr. Burroughs. H. R. Burroughs, Jun. Am. Soc. C. E. (by letter).—The writer was much interested in Mr. Goodrich's paper, as it recalled a test which had come to his notice and may be worthy of mention.

The writer was required to make an inspection of a reinforced concrete building, the report having been prompted by the fact that, upon stripping the forms, the concrete was found to be porous, with many visible pockets. After considerable investigation, it was concluded that it would be necessary to remove the porous parts and refill the places thus made vacant. The expedient of bonding new concrete to old was resorted to, as the defective places had already been poured several weeks. No apprehension, however, was displayed in recommending this method of procedure, which was undertaken and, to all appearances, carried out with success and satisfaction.

In view of this undertaking and incident thereto, the Superintendent in charge conceived the idea of making a rough bonding test, more to satisfy his personal curiosity than to arrive at any conclusion. He selected a barrel and poured into it the regular concrete mixture, as used on the work, until it was one-third filled; this was permitted to set for seven days, when the second third of the capacity of the barrel was poured; this also was permitted to set for seven days, when the last third was poured, filling the barrel. The barrel was then set aside for two weeks, when the staves were stripped from the concrete, exposing the concrete mass. It was noted that the lines of cleavage were scarcely visible, the whole exhibiting an appearance of continuity and of being monolithic.

It was then attempted to break this concrete core by well-directed blows from a sledge. It required several severe and direct blows, however, to start a break, the ultimate rupture occurring, as might be expected, on a line of junction between two zones of different times of pouring.

The bond or cohesion displayed, however, seemed remarkable, inasmuch as no attempt had been made to effect a union of the parts, the surfaces not having been washed or cleaned.

Mr. Belzner. Theodore Belzner, Jun. Am. Soc. C. E. (by letter).—The writer has read with much interest the description of these laboratory experiments on the bonding of new to old concrete, and also the published deductions from tests made by Messrs. Perry and Mesnager.

There are many methods for bonding concrete, but the writer will confine his discussion to that in which the strength depends on the degree of adhesion of concrete to concrete.

Excellent results in bonding can be secured in the field by conscientious treatment and intelligent supervision, although such results cannot be compared with those of the laboratory, as, in the latter case,

the experiments are made under conditions which are practically impossible to secure in the field. Mr. Belzner.

Laboratory experiments have determined that roughening the old concrete surfaces and applying a layer of cement paste have given the best results. The writer has used this method on construction work in the New York Subway and on other engineering work. He has had occasion to examine concrete jack-arches, walls, etc., in which great care was exercised in the bonding, and while these arches appeared to be monolithic for a year or more after their construction, upon close examination, they revealed fine hair-line cracks on the surface. These cracks could be readily traced at the junction of the work of one day with that of another, indicating a break between the bond. On many other occasions he has observed breaks in the bond of concrete constructed under less careful supervision, the joints of which could easily be traced between the layers of concrete. This was proved conclusively by examining concrete which had been demolished and in which the joints had been separated. The writer also recalls several instances when engaged in locating leaks in steel-concrete construction and in jack- and roof-arches,* where surface water had percolated through the horizontal joints. These investigations have convinced him that perfect joints in concrete are a fallacy, experience having taught him that the different days' work can always be traced, despite any precautions which may have been taken. It is his opinion that investigators should continue their laboratory experiments along this line, but before acid and other treatments are permanently adopted in the field (even though good results have been obtained on a small scale), the present methods should be continued (roughening the old concrete surfaces and applying a cement paste) until acid treatments, etc., have proved positively their practical efficiency.

The only possible way of securing a perfect monolithic structure is by carrying on the work continuously, day and night, until finished. This can be done, at times, on small structures, but is practically impossible with structures of magnitude.

James L. Davis, Assoc. M. Am. Soc. C. E.—The speaker has made a small series of bonding tests for the Board of Water Supply of the City of New York, under the direction of Ernst F. Jonson, Assoc. M. Am. Soc. C. E., Engineer Inspector. Mr. Davis.

The purpose of the tests was to determine the efficiency of a proprietary bonding compound. The test specimens were beams 6 by 6 in. in cross-section, and 30 in. long. The concrete was a 1:3:5 mixture, with ordinary sand and gravel aggregate. The tests were conducted as follows:

* *Transactions*, Am. Soc. C. E., Vol. LI, p. 130.

Mr. Davis. Three beams were broken by central loading on a 26-in. span at the age of 28 days. All broke very nearly in the middle, and gave ordinary strength values. Each half of the three beams was put into a wooden mould similar to those in which they were cast, leaving one-half of the mould empty. New halves were then cast, restoring the beams to their original dimensions, making six specimens. Before casting the new halves, the fractured end surfaces of the old beams were wetted and covered with a cement grout of as heavy consistency as could be applied with a brush. In making the grout for three of the beams, the bonding compound was dissolved in the mixing water as directed by the makers. For the other three, the blanks, the grout contained none of the bonding compound. Care was taken to work the fresh concrete thoroughly in the vicinity of the joint, using a bricklayer's trowel. This expelled the air and insured contact with the old surface.

After 28 days, the beams were again broken in the same manner as before. The breaks occurred in the new concrete about $\frac{3}{4}$ in. from the joints, in one beam touching the joint at one point. There was no difference in the results where the bonding compound was used and where it was not. The result in every case was a perfect bond within the limit of the strength of 28-day concrete.

Mr. Slocum. C. L. Slocum, Assoc. M. Am. Soc. C. E. (by letter).—The writer is somewhat interested in Mr. Goodrich's investigations and experiments, and also in the general conclusions drawn from the laboratory experiments by Messrs. Matthews and Watson,* because, in a more practical way, on some reinforced concrete work, lately finished, and with which he was connected as Assistant Engineer, he felt it necessary to suggest and to have made similar experiments, though perhaps a little more crude, in order to gauge properly the final results and the worth of the constituent materials.

The structure for which these continuous tests were made is a double-track trolley viaduct, consisting of some thirty-five spans, each 30 ft. from center to center of columns. This viaduct begins and ends at two street crossings, and is intersected by two others in its total length of some 1 200 ft. Briefly, its typical arch span consists of floor-slabs which are supported by, and are a part of, four arch ribs which carry the two tracks, balustrade, and occasional platforms at street crossings. The two inside arch ribs, with the slabs, are connected to, and carried by, a floor-beam, at the third points, which, in turn, supports the entire structure on two columns; the outside ribs carry the platforms and balustrade, and connect directly to the columns.

* "The Action of Frost on Cement and Cement Mortar, Together with Other Experiments on These Materials," by Messrs. Ernest R. Matthews and James Watson, *Proceedings*, Am. Soc. C. E., January, 1909.

In other words, this structure is of the usual delicate and graceful proportions common to reinforced concrete work. Mr. Slocum.

The construction, of necessity, was begun in the middle of summer and continued throughout the winter, as favorable conditions would permit, so that its completion was assured in the early spring. In work of this kind some experiments were necessary in order to enable those intrusted with its construction to know what to expect in regard to the strength of the concrete after the attainment of a certain age, so that, for instance, the falsework could be used again as many times as possible. One of the principal objects, in carrying on these experiments parallel with the actual construction, was to ascertain the effect of a wide range of temperature on concrete work.

With each day's work of concreting an arch, from six to twelve 6-in. concrete cubes were cast under conditions as nearly as possible like those under which the concrete in the particular arch was put in.

The blocks were handled in various ways in order to estimate their strength; some were buried in moist or wet ground, and some in dry ground; others were put in exposed places in order to subject them to the same conditions as the actual work. All work was done on the site of the construction. Some of the blocks were kept under wet cloths, while others were placed in a warm office to dry out quickly. Several blocks were frozen in various stages of setting up, and then thawed out, and aged.

Each set of blocks belonging to a particular arch was crushed at the age of 7, 10, and 14 days, 1 month, 3 months, and 6 months. No refinements were used in obtaining an even bearing surface for these 6-in. cubes when they were crushed in the testing machine, except to cast them with as smooth surfaces as possible. The blocks were made by the men who made and deposited the concrete in the particular arch, and received no more attention than the arch concrete. Inasmuch as these tests were rather crude field experiments, when compared with the usual laboratory refinements, they were only valuable in regard to the general average results. The results corroborated well-known standard information, and provided a ready means of studying closely the mixing of the concrete. During the early part of the work some of the cars of crushed stone contained considerable dust and dirt. The blocks showed an increase in strength when the stone was wetted and cleaned before using. The effect of the range of temperature during the winter months was marked in the strength of these cubes, for it took about twice as long to attain the same strength as in the milder weather of fall. Consequently, when cold weather came, it was plainly seen that the falsework could not be struck as soon as in warm weather, but depended on the range of temperature at the particular time. Inspection of these broken cubes enabled the engineers to modify the

Mr. Slocum. constituents of the mix in order to keep the percentage of voids as low as possible. These tests also showed that it was sometimes advisable to scrutinize the cement closely.

The concreting of one arch span constituted a day's operation, being preceded by the setting of the forms and centers and the placing of the steel. Consequently, the position and method of making a joint for succeeding arches and concrete operations were matters of much concern. After much discussion it was determined to make the joint on an inclined plane corresponding to the skewback of the forward arch ribs at the junction of the upper surface of the floor-slab and the far edge of the floor-beam, the inclination being about 60° from the horizontal. In his specification, the writer inserted the following clause to cover the one particular and important joint:

"The joints, at the beginning or end of a day's work, shall occur at the floor-beam, on the line corresponding to the skewback of the arch. All such junctions of new and old work shall be rabbeted; if smooth, it shall be picked and roughened, well washed, and, before making the junction with the adjoining span, shall have a thin layer of clear cement spread over it."

In the thirty-eight joints necessitated by the thirty-five arches and six abutments, practically one method was used to obtain as perfect a bind as possible between abutting arches or between an arch and an abutment. At all times and in all cases, the greatest care was exercised to have the surface of the old concrete thoroughly clean. To insure this an inch or more was picked or drilled off, depending on the hardness of the old concrete. The new surface was then thoroughly washed off, sometimes with clear water, at other times, with a solution of muriatic acid and water, and then with clear water, accompanied by a thorough sweeping and scrubbing with wire brushes and stiff brooms. Just before the fresh concrete was placed, a thick neat-cement wash was brushed over the contact surface of the old concrete.

The collection and presence of much laitance was a constant source of annoyance, particularly during the warm months. This scum was scooped or shoveled off as much as possible during the concreting operations, and when it had hardened on the surface of the joints, it was loosened by picks, drills and wire brushes.

In addition to the regular reinforcement steel, common to the structure at the plane of junction, twisted bars ½ in. thick, at 1-ft. centers, were placed across the joint. They were of such a length as to develop their full strength in adhesion on each side of the joint.

The efficiency of these joints is indicated by the following facts: The two intersecting streets divide this entire work into three parts, and in the design and construction no special provision was made for taking the effects of contraction and expansion in these parts.

Since the completion of the work there has been a record change of 40° in temperature in about 36 hours. The structure itself, perhaps on account of the nature of its reinforcement, may have absorbed the effects of contraction and expansion, for none of these bonded joints has opened, and, furthermore, the track surface of the viaduct has been covered with moisture in the form of rain, snow and ice, and nowhere have these joints leaked, or have shrinkage cracks appeared. Mr. Slocum.

It may be stated that nothing was added to the concrete to make the structure water-tight, except to have a wet mixture, and, without the water-proofing, the entire structure of 1 200 ft. is practically water-tight.

Eugene W. Stern, M. Am. Soc. C. E.—The speaker had a practical illustration recently, as to the strength of the bond between new and old reinforced concrete which may be of interest. A large floor had been constructed in which the beams, girders, and slabs were of rein- Mr. Stern.

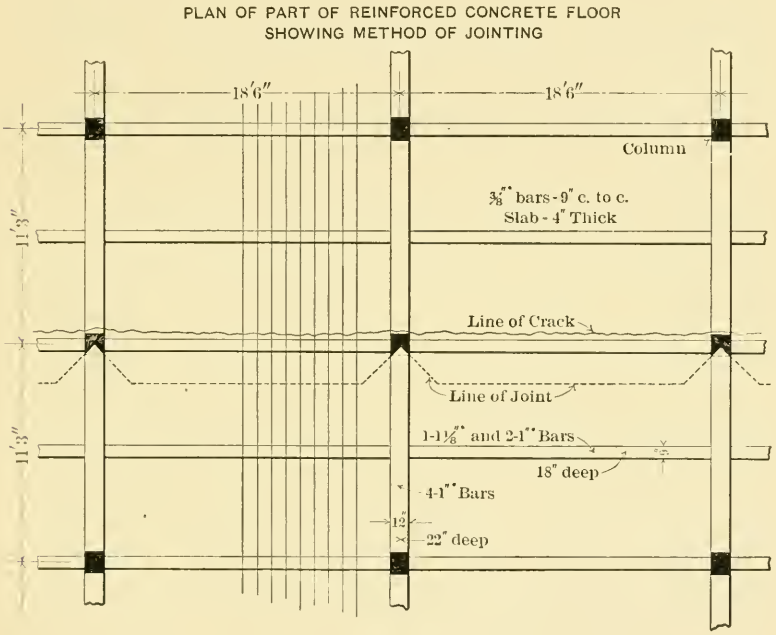


Fig. 2.

forced concrete. The floor was 270 ft. long and 185 ft. wide. The work was carried across the building without a joint, by continuous work, but was jointed about every 22½ ft. in the length of the building. The reinforced concrete girders were jointed on the columns, a 45° pocket

Mr. Stern. being left in the columns for this purpose. The slabs were jointed on a line at 45° to the axis, starting from the column, until about the quarter point of the span was reached, when it was made on a line at right angles to the girders and reinforcing bars, and parallel with the joists, as shown on Fig. 2. Before bonding the new work to the old, the latter was thoroughly cleaned with a brush and water and wetted, and then neat cement mortar was applied.

The work was finished during the summer and fall. In the winter of 1908, during cold weather, a shrinkage crack opened up across the building, about 60 ft. from the north end, close to a row of columns, and very near a line of bonding between old and new work, but in no case did the concrete crack at this bond line, thus showing the remarkable strength of the bond. This crack extended through slabs and girders, and was at right angles to the reinforcing bars.

Mr. Fort. E. J. Fort, M. Am. Soc. C. E.—So far as conclusions from these experiments are justified, it seems fair to infer that present practice in bonding new concrete to old is amply sustained, for the majority of carefully written specifications call for that method of procedure which is shown to have produced the most satisfactory results.

If additional data could be obtained, covering the use of various special compounds and processes, for which extravagant claims are sometimes made, a real service would be rendered to the Profession.

It is gratifying to find that such satisfactory results can be obtained by the use of acid. Where the usual method of procedure is not practicable, a satisfactory alternative is always available.

It is through the accumulated evidence of such experiments as these that practice in many cases may be standardized, and Mr. Goodrich's paper is valuable in that it puts on record the results of carefully made experiments.

Mr. Lewis. Myron H. Lewis, Esq.—The speaker had had occasion to investigate the question of bonding old to new concrete work. About two years ago, having received some circulars from a large water-proofing company, claiming that it could get a bond of 140 lb. per sq. in. by the application of its product to an old concrete surface, the speaker, desiring to know whether that claim was *bona fide*, or whether it was simply a trade catch advertisement, sent to Professor Black, of Columbia University, specimens of water-proofed Portland cement, and a cement to which no water-proofing compound had been added. Professor Black was requested to test these specimens, but was not informed of the difference between them, they being designated simply as No. 1 and No. 2. The results, while not at all conclusive, show that, as far as bonding was concerned, the claims of the company in question were quite well verified, much to the speaker's surprise. This is mentioned only as a suggestion to those who are working in the laboratories, and

it is hoped that there will be further experiments in order to see whether additional tests will confirm this result. Mr. Lewis.

These tests were made in the same manner as those made by Mr. Goodrich, using ordinary briquettes, filling half the mould in the first operation and the remainder at the end of 7 days.

Four briquettes of each material were broken. The proportions were 1:2:5. The ordinary cement briquettes broke at 135, 137, 130, and 160 lb., the average being 140.5 lb. The briquettes made with water-proofed cement broke at 160, 163, 172, and 178 lb., the average being 168 lb., showing an increase of 20 per cent. The lowest breaking point of the water-proofed series was as high as the highest of the ordinary series. The breaks were along the junction of the older and newer portions of the briquettes.

While this was only a 7-day test, and may not be of any value, it is an indication that further experiments may be of some use, and may bring out some interesting facts.

Furthermore, a great deal of water-proofing work has been done by the application of specially-treated cement mortar coatings, in such buildings as the Hudson Terminal, the Baronne Building, in New Orleans, the McClure Building, in Long Island City, the City Investing Building, and in many other structures in various parts of the country.

When applying the coating, the contractors take every precaution to get a good bond, and, unless this is obtained, the work is likely to go to pieces very quickly, especially where there is hydrostatic pressure, as there is in many buildings, the foundations being many feet below tide water.

The speaker has prepared a set of specifications giving detailed instructions for bonding a cement coating to an old concrete wall, and also the precautions which should be taken. In most cases, where the wall is of any age at all, either a bonding compound or a commercial acid should be used, and, as a rule, the contractors find that it pays to use an acid or a bonding compound—the latter being principally one of the commercial acids prepared in more convenient form.

When acids are used and the specifications are intelligently followed, the result is a bond so strong that the mortar will break before it will separate from the wall. In the Baronne Building, in New Orleans, a number of large hardened-steel chisels were broken in endeavoring to remove a portion of the cement coating applied in this way. An area of about 200 000 sq. ft. of coating has been laid in accordance with these general directions by the various companies engaged in work of this kind, and in a large majority of cases the bond has held perfectly, under heavy pressure and trying conditions.

That the use of the water-proofing compound in the cement is

Mr. Lewis. largely responsible for the increase of the bond is borne out by this work, and appears to substantiate the facts indicated by Professor Black's tests.

The complete specifications referred to may be found in the speaker's paper on water-proofing.* The following is a summary of the directions for bonding cement coatings to concrete walls:

1.—The old concrete surface should be thoroughly chipped, not more than two days prior to the application of the coating. The chipping may be greatly facilitated by a previous application of muriatic acid or a bonding compound, such as "Bondsit," the strength of the solution depending on the age of the wall; or the use of the bonding material may be deferred until the chipping has been completed.

2.—In case acid or bonding powders have been used, all unspent acid should be removed by rigid application of the hose, immediately after the acid treatment has reached a satisfactory stage.

3.—The dust, dirt, and loosened material must be completely removed, either by patient scrubbing with stiff brushes, by water nozzle, steam jet, or other suitable means. An absolutely clean surface should be obtained, not more than 24 hours before the application of the coating.

4.—All holes should be filled, large holes with a water-proofed concrete, and small holes with a water-proofed mortar. Before filling the holes, the old surfaces should be drenched and a slush coating applied, as described below.

5.—Just before the main cement coating is to be applied, the entire wall should be drenched and soaked to its full hygrometric capacity.

6.—Before the wall shows marked signs of drying, a slush coating should be applied quickly and uniformly with a palmetto. This slush coating should be made by a thorough mixing of water-proofed cement in water, to the consistency of cream.

7.—Before the slush coating has dried, the first mortar should be applied as a scratch coat, $\frac{1}{4}$ to $\frac{3}{8}$ in. thick, and pressure brought on the trowel to push the coating on and obtain a uniform bearing. The scratch coating should be made by mixing 1 part of water-proofed cement with 2 parts of clean, well-graded, moist sand, and enough water to obtain the proper consistency.

8.—The scratch coat should be troweled to a fairly good surface and scratched before hardening.

9.—Upon the scratch coat, before its final setting, the finishing coat, of sufficient thickness to obtain a total thickness of $\frac{5}{8}$ in., should be applied. This should be pushed on hard and uniformly, and troweled and floated to a true surface, free from pin-holes, projections, or other defects. The composition of the finished coating should be 1 part water-proofed cement to 2 parts sand, well graded and previously moistened.

10.—If not feasible to apply the finishing coat until after the scratch coat has already set, the latter must be thoroughly rinsed and slush-coated before the finishing coat is applied.

* Read before the Municipal Engineers of the City of New York, November, 1908.

FIG. 1.—APPLYING CEMENT COATING TO CONCRETE WALLS AND COLUMNS.

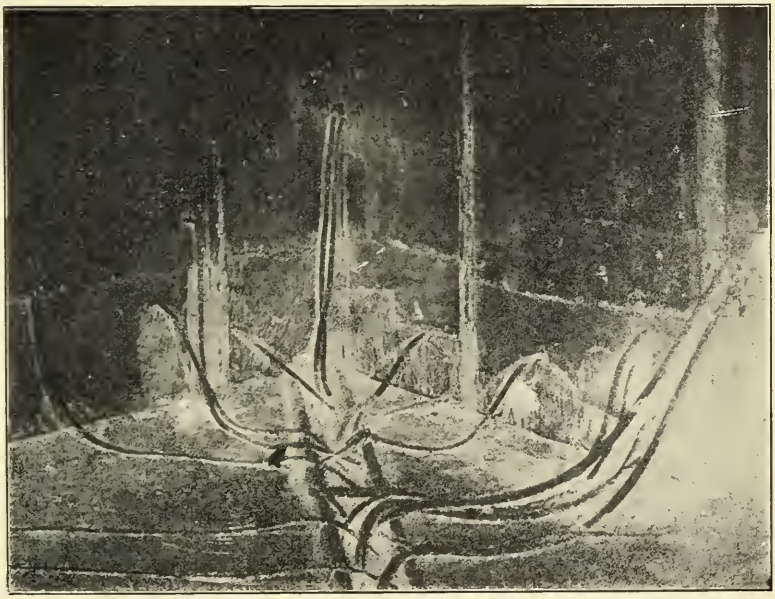


FIG. 2.—METHOD OF DRAINING WALLS, UNDER EXTERNAL HYDROSTATIC PRESSURE. DURING APPLICATION OF CEMENT COATING.

11.—The floating of the finished surface should be done from the bottom of the wall up. Mr. Lewis.

12.—When the work has been completed, all bad and defective work should be cut out and replaced in the same manner as above described.

13.—When the work has thoroughly hardened, the wall should be sounded with a light hammer, in order to discover any loose or hollow portions, and these must be cut out and replaced.

14.—In leaving a portion of work for the day, the section being finished should be left with straight edges. When the new work is to be started, the old edges should be roughened up, by chipping and roughening with a trowel, and then rinsed and slush-coated, as already described.

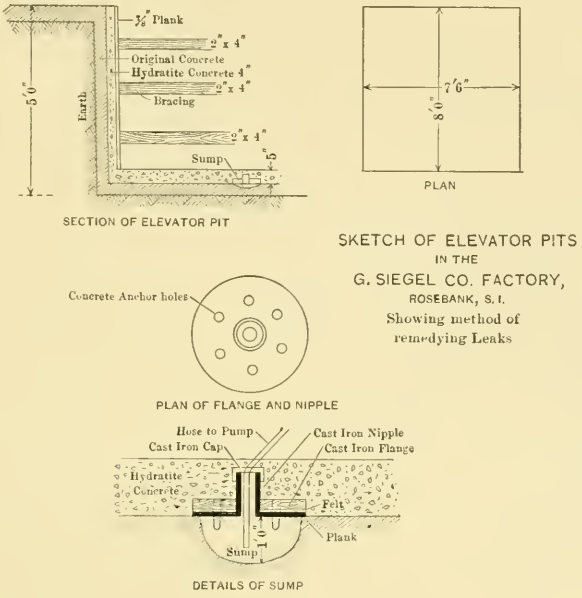


FIG 3.

The water-proofed cement referred to herein is prepared by adding to the dry cement 2% of a stearic water-proofing compound, such as "Hydratite," "Medusa," etc., according to the directions furnished with the same.

The compound serves a two-fold purpose. It appears to increase the adhesion between new and old work, and also permits a reduction in the amount of troweling necessary to obtain impervious work. Experience indicates that imperviousness and bond can be obtained without the addition of the compound, but water-proofing contractors using these methods (termed "The Integral" by the speaker) find that the reduction in the labor cost of troweling and floating is sufficient

Mr. Lewis. to offset the slight additional cost of the material, and they always use it when they are permitted.

The additional cost of the materials alone for the standard compounds may be taken at about one cent per square foot of wall.

The following illustrations may be of service to those interested in work of this kind.

Fig. 3 is a section of the elevator pits in the Siegel Factory, Rosebank, Staten Island, in which cement coating was applied in general accordance with the methods described herein.*

Fig. 1, Plate V, shows the method of applying cement coatings to the walls and columns of the Baronne Building, New Orleans, La.

Fig. 2, Plate V, shows the method of bleeding walls during the application of water-proof cement coating to walls under pressure. Cast-iron pipes, having cutting edges, are driven into the walls to drain them; these pipes protrude about $\frac{1}{4}$ in., and are connected by hose to the sump. The coating is applied to the dry portions of the wall surrounding the pipes, and, when finished, pine plugs are driven into the pipes, and the latter are covered with the coating.

In concrete mass work, the joining of older to newer portions can be accomplished in substantially the same manner as that above described for the application of cement coatings. The procedure for the best results should be as follows:

1. Treat the old surface with acid or bonding compound.
2. Remove the unspent acid by washing.
3. Drench the old surface.
4. Apply a slush coating of water-proofed cement before the surface has dried.
5. The concrete immediately adjacent to the slush coating should be laid before the latter has dried, and should be mixed preferably with water-proofed cement.
6. The mass concrete should then be deposited as usual.

Mr. Briggs. W. C. Briggs, M. Am. Soc. C. E. (by letter).—The vacuum process of cleaning might be applied advantageously to the cleaning of an old concrete surface. A blower, operated by an electric motor or a gasoline engine, would be inexpensive and quite portable.

Mr. Harper. Frederick C. Harper, Jun. Am. Soc. C. E. (by letter).—In the construction of walls for the basement of a certain building, the exterior surface was to be plastered with 1:1½ mortar. Above the ground this plaster was to be $\frac{3}{4}$ in. thick and to have a float finish. Usually, the plaster was placed from 36 to 48 hours after the forms were removed, the age of the concrete being from 3 days to 2 weeks. The method of procedure was first to wash the walls well with water, applied with a plasterer's brush. Then, before the water had soaked

* A full description may be found in *Engineering News*, August 13th, 1908.

in, they were washed with neat cement grout, and immediately afterward the plaster was put on. The foreman gave careful attention to the work, seeing that no time was lost between the three steps. Mr. Harper.

That these careful operations gave good results is evinced by the fact that when, in one place, the concrete was cut out to change the elevation of a window, the lines of cleavage went back into the concrete, showing that the bond between the concrete and the plaster was stronger than the concrete itself. The plaster had been in place about a week.

This experience is an exception to the oft-stated rule that it is impossible to make a coherent plaster finish.

The following notes relate to the construction of two concrete park pavilions with reinforced concrete floors.

The instructions with regard to the floors were that the top coat was to be put on immediately after placing the slabs, and, if by any mistake it were not immediately placed, the thickness was to be increased from the regular $\frac{3}{4}$ in. to a minimum of $1\frac{1}{2}$ in. The superintendent—a technical graduate, fresh from school—left this work to a "finisher." In the first pavilion the slab was not finished until late in the evening. The finisher and the superintendent covered it with water, thinking that the concrete would not set, and left it until the next morning. Then the finisher used a $1:1\frac{1}{2}$ mortar, and placed the top coat, neglecting to increase the thickness. The surface cracked so badly that it will be necessary to replace it. In floors of this kind the expansion or contraction is confined by the surrounding wall.

The instructions for the floor of the second pavilion were to construct the top and base at the same time, increasing the top thickness to $1\frac{1}{2}$ in., and, around the floor, to cut a groove extending through the top coat. The groove, being objected to by the owner, the floor was made according to the first instructions. It, also, cracked slightly. As in both cases the cracks appeared before the centers were removed, they were not due to deflections in the slab. The floors were kept wet after being laid.

The writer would like to see an analysis of the stresses, due to shrinkage in setting and temperature changes, in a structure of this kind.

E. G. Walker, Jun. Am. Soc. C. E. (by letter).—The experiment detailed at the end of Mr. Goodrich's paper, on a reinforced concrete beam in which the concrete was placed at different times, is of great interest in view of the fact that in structural work beams sometimes occur in positions in which they must be built up in two operations. In setting out to make this test, Mr. Goodrich had three important questions to answer. These are fully detailed on page 268, and it is to be regretted that he was only able to test one beam for this purpose, as it would seem to be necessary to carry out a far more extended series Mr. Walker.

Mr. Walker. of tests in order to settle fully the points raised. In the test actually carried out it appears to the writer to be an undesirable feature that the experimenting in connection with bonding along a diagonal compression surface was carried out in the same beam as the investigation of the effect of a horizontal joint. The writer thinks that it is quite probable that the presence of the two joints in the same beam must have caused a certain amount of masking of phenomena due to the overlapping of the effects set up simultaneously by two different sets of causes. This appears to him to be at least a contributory reason for the result enunciated in Conclusion (*b*) on page 269. On a first examination of this, it does not seem feasible that the joint can be actually stronger than the continuous concrete, and it seems possible that the explanation of the experimental result may be different from that assigned by the author. On comparing the various diagrams given in Fig. 1, it is noticeable that the diagonal failure occurs in the neighborhood of the junction of the three pieces of concrete marked 1, 2, and 3, as shown in Fig. 4. It is impossible to state how much the upward inclination, *c b*, of the line of division between Sections 2 and 3, at or near the point where the diagonal failure crosses the line of the horizontal failure, may have influenced the result of the test by altering the distribution of shear and diagonal stresses. In any subsequent experimental work on this subject of stopping off concreting, the writer is of the opinion that it would be preferable to experiment with beams in which the concrete was placed to the full depth of the beam in one operation, so that there would be no horizontal joint (Fig. 5). It would then be possible to determine the effect of a diagonal joint, apart from any other potential or actual cause of variation introduced by the presence of the horizontal joint. The practical importance of the latter justifies its behavior being made the subject of separate experiment. This course would seem all the more desirable in view of the fact that the two kinds of stopping off are unlikely to occur together frequently in practice, and a beam with a single line of division would thus approach more nearly to the actual conditions which obtain in the field.

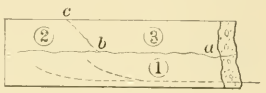


FIG. 4.

FIG. 5.

In considering the horizontal joint, it is noticeable, in the first place, that the joint was made along the neutral axis of the beam, and, following the case which the author appears to have had chiefly in mind, of a deep beam on the face of a building, over a door or window opening and carrying a floor at the plane of the joint, the load is applied also at the neutral axis. The results obtained lead the author

to the conclusion that "the beam should be designed of a height only up to the joint." No experiments have been made with the plane of the joint in any other position, either above or below the neutral axis, and the experimental evidence is thus limited. In practice, the position of the plane of the joint may vary between the limits of the depth of the beam, and the universal application of the author's conclusion would lead to impracticable results in some cases. It is easily possible to conceive of a case, such as shown in Fig. 6, in which the floor slab is connected to the girder only a short distance above the level of the tensile reinforcement of the latter and far below the neutral axis, $N A$. In that case what is going to be the effect of a break in continuity in the concrete at the floor level? It would be obviously impossible in such a case to calculate the beam as of depth, $p q$, and some different treatment is necessary. As far as direct stresses are concerned, there is no difficulty, for, since the tensile resistance of the concrete is not to be considered, it makes no difference whether the concrete below the neutral axis is in one piece or is divided up by a plane of weakness. The result thus appears to turn on the distribution of, and the power of the beam to resist, diagonal tensions and compressions. Perhaps the author will give his opinion of such a case as this.

Mr. Walker.

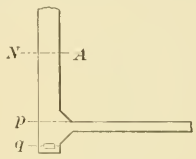


FIG. 6.

It is noticeable that when the test load was removed from the neutral axis to the top surface of the beam (Conclusion (*b*) on page 269), the cracks completely closed up, indicating that in the case of a very deep beam or rib built up in two operations but with a load applied above the level of the horizontal joint (Fig. 7), the existence of the latter does not appreciably weaken the beam. It would be of interest to know how the author would propose to deal with this case, for which he gives no conclusion in his paper.

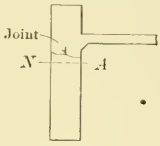


FIG. 7.

E. P. GOODRICH, M. AM. SOC. C. E. (by letter).—Subsequent to the presentation of the paper, the writer's attention was called to the following pertinent items:

Mr. Goodrich.

Concerning methods of securing a superior bond, James Owen, M. Am. Soc. C. E., says:*

"It is a generally accepted fact that it is very difficult to obtain a perfectly homogeneous connection with work finished over-night and built on the next day. * * * In a large proportion of concrete construction, the joint, where one section is put upon the other, is very noticeable when the work is completed.

* * * * * * *

* *Transactions*, Am. Soc. C. E., Vol. LXI, p. 384.

Mr. Goodrich. "The speaker's attention was first called to the bond question in the case of a Paterson bridge which was carried away by a freshet. On examination, the break was found to have occurred on a line of work where two sections had not been thoroughly bonded in construction.

* * * * * * *

"The speaker tried the experiment of making the last run of the machine very wet, and found this somewhat efficacious. This run was so wet that the next morning the water had all collected on the top of the pier, with very slight setting on the surface of the concrete. The water was swept off and the new joint made, and thus the difficulty was overcome, in a measure; but, if there are such joints in pier construction between high and low water, such trouble is likely to occur."

Concerning specifications for such work, Section 7, Paragraph 2, of the Regulations of the Royal Prussian Ministry of Public Works for the Construction of Reinforced Concrete Buildings, reads as follows:

"When work is to be done on hardened concrete, the old top surface must first be roughened, swept clean, wetted, and coated with a thin cement grout, before new material is deposited."

As a further source of information concerning the results of cross-breaking tests, in comparison with true tension experiments, Taylor says:*

"The results of cross-breaking tests * * * expressed by the formula $\frac{3\,w\,l}{2\,b\,h^2}$, * * * have been shown to give values from 1¼ to 3 times the tensile value, depending upon the length, dimensions, richness, age and method of treatment of the specimen. For seven and twenty-eight day tests made on prisms of 1:3 sand mortar, one inch square and on a span of 10 inches the factor is very nearly 1.5."

* A table is given showing a large number of comparisons.

Further comparisons can be obtained from the "Results of Tests of Portland Cement Mortars and Their Constituent Materials."†

The ratios computed from the results on different sands, all with the same humidity, cement mixture, age, and size of specimen, varied from 1.63 to 2.54, with an average of 1.95, and a ratio of the average results of 2.02.

After the publication of the paper in *Proceedings*, a beam was broken which, in all respects as to age and size, was identical with the one described, except that no joints were left in the work. The beam broke suddenly, through a failure of diagonal tension, at a center load of 5 150 lb. This compares with 3 500 lb. in the original beam.

It is true that there may have been a masking of phenomena during the test of the first beam, but close observation of its action under

* "Practical Cement Testing," pp. 233–234.

† Bulletin 331 of the U. S. Geological Survey.

FIG. 1.—ORIGINAL BEAM, SHOWING END WHICH FAILED UNDER THE TEST LOAD.

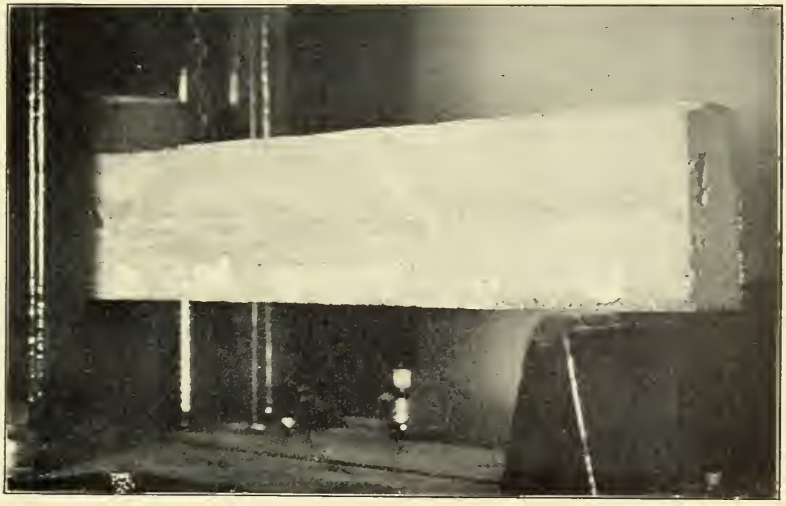


FIG. 2.—ORIGINAL BEAM, SHOWING END WHICH DID NOT FAIL.

load seemed to the writer to point to the conclusions recited in the paper. Mr. Goodrich.

Two views of the original beam after failure are shown on Plate VI. Fig. 1 is a view of the end which failed, showing a crack extending diagonally downward through the mass of the concrete, a horizontal crack between the layers, and a fine vertical crack. What appears like a diagonal crack extending upward to the right is only an artificial joint, which remained unaffected. Fig. 2 shows the end which did not fail, even though an artificial joint had been left where failure would be expected to occur.

Analyzing the conditions of internal stress in the beam will throw some light on the probable stresses involved and the action of the beam under load. Certain assumptions have to be made concerning conditions, in order to simplify the problem so as to bring the essentials into clear view.

(*a*).—The dead weight of the beam will be ignored.

(*b*).—The effects of strains in altering stresses up to the moment of actual cracking will not be considered.

(*c*).—It will be assumed that the load would act in the same manner in producing internal stresses (until such time as cracking takes place), whether it is applied at top, bottom, or other point on the member.

As to Assumption (*a*), with a beam weighing 200 lb. and a center load of 2 000 lb., the average approximate percentage of stress ignored is

$$100 \times \frac{\frac{1}{8} \times 200\ L}{\frac{1}{8} \times 200 \times L + \frac{1}{4} \times 2\,000 \times L}$$

$$= 100 \times \frac{25}{25 + 500} = \frac{2\,500}{525} = 4\% +$$

As to (*c*), experiments made by the writer show that the assumptions usually made do not hold with concentrated loads. They always produce strains and stresses which can be explained only on the assumption of a very rapid and quite considerable distribution of load.

With the assumption thus made, the following conditions approximate:

1.—The distribution of direct compressive and tensile unit stresses over the vertical height of section are as shown in Fig. 8 (after Mörsch).

2.—The distributions of unit shearing stresses on vertical and horizontal planes are as in Fig. 9.

Since the load is considered as concentrated, the shear is to be assumed as constant throughout the length of the beam on any hori-

Mr. Goodrich.

zontal plane, simply being of opposite signs on opposite sides of the load. For all practical purposes, then, the shear may be considered as constant between the neutral axis and the plane of the reinforcement.

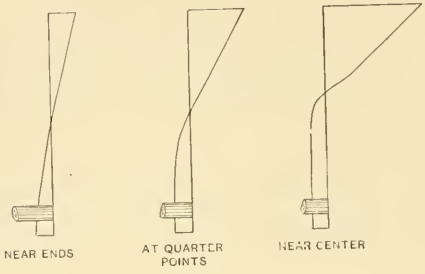


FIG. 8.

FIG. 9.

3.—The lines of maximum diagonal tension are then approximately as shown in Fig. 10. Cracks will then run across these lines and at right angles to them when no vertical stirrups are used.

4.—The direction and magnitude of the diagonal tensile stresses along the neutral axis and along a vertical section may be indicated, as in Fig. 11. Cracks would open only at right angles to the directions of the arrows. Theoretically, therefore, the presence of the diagonal joint near the left end of the beam (as shown in the diagram, Fig. 1) should have no appreciable effect on the distribution of internal stress, especially as compared with the one at the other end of the beam.

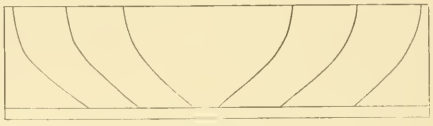


FIG. 10.

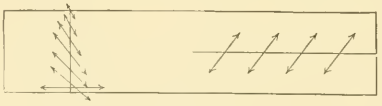


FIG. 11.

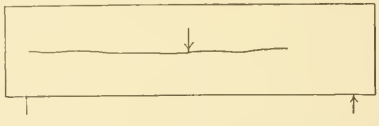


FIG. 12.

It is thus extremely doubtful whether the diagonal joint, *c b*, of Mr. Walker's Fig. 4, had any influence whatever on the conditions of the problem. This joint was evidently fully as strong as the one at the other end, and was not the source of weakness which caused the start of the diagonal crack near the left end. Its cause is more likely to have been the presence of the end of the bent-up reinforcing rod. Finally, the fact that the left joint was parallel to the direction of action of the diagonal tensile stresses near that end, would strongly militate against its being the source of any trouble.

Ignoring, then, the presence of either diagonal joint, the beam can be considered as one in which a horizontal joint existed over three-fourths of the length of the beam, starting at one end. (See Fig. 12.) Only the vertical components of the stresses shown in Fig. 11 will be effective in separating the upper and lower parts, with the load applied at the level of this joint, splitting would be expected to start near some point of weakness and extend rapidly over the full length of the joint, at least to a point over the left support and perhaps into the mass concrete at the right end. As soon as this split took place, the lower half of the beam would deflect much more than the upper section, the latter only being bent by the rigid connections which exist at its ends. (See Fig. 13.) The tendency would obviously be to crack either upward or downward at the end of the horizontal crack, as illustrated in Fig. 14. Mr. Goodrich.

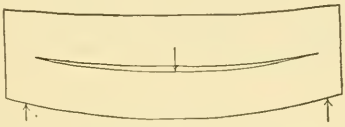


FIG. 13.

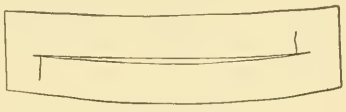


FIG. 14.

If the load were shifted from the center to the top of the beam before the vertical cracking took place, the horizontal crack would obviously close up and remain closed until a new condition had been set up. The top portion would act like a spreader to distribute the load over a considerable length near the center of the bottom section. Since the top section had no horizontal reinforcement, it would tend to break into several short sections, only the center one of which would be effective in producing bending in the bottom part. This condition can be illustrated by Fig. 15, and shows why the top section cracked vertically at what was evidently its weakest point near the end of the reinforcing rod.

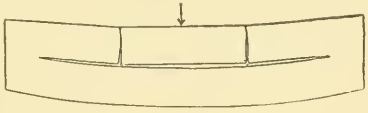


FIG. 15.

The constancy of the shear between the neutral axis and the bottom of the beam shows that the diagonal tensile stresses remain nearly constant in direction and actually increase slightly in magnitude, so that their vertical components are at least as large as at the neutral axis, and their effect on any natural joint would be equally destructive. It is essential, therefore, in any such section as that of Mr. Walker's Fig. 6, to use "ample reinforcement, consisting of stirrups or numerous diagonal rods," or else design the beam "of a height only up to the joint," as recommended in the paper. With a slab applied at a point more than half the height of the beam section above its bottom, the

Mr. Goodrich.

slab will usually be so stiff that it will form an effective flange, if properly reinforced and tied to the wall-beam, so that the portion of the beam above the slab may be ignored. With a joint just below the slab, the action would be almost certain to be like that of the test beam, and only the height recommended can properly be used in designing. The existence of the joint will always weaken the beam materially unless ample web reinforcement is used.

The writer doubts whether the vacuum process would be able to break off the surface glaze, the removal of which is essential to securing a perfect bond.

It is to be observed, in connection with the use of some of the water-proofing compounds now on the market, that many tests have shown that their admixture does not increase the strength of the mortar. In any case, only a very small tensile strength in bond is ever developed in connection with cement water-proofing coatings, since a head of even 20 ft. of water will produce a stress of not quite 9 lb. per sq. in., which is very low in comparison with results required in other locations.

This shows that it is not so much the strength of the bond which is involved, for water-proofing work, as the imperviousness of the coating.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1110

NICKEL-STEEL EYE-BARS FOR BLACKWELL'S ISLAND BRIDGE.*

By William R. Webster, M. Am. Soc. C. E.

With Discussion by Messrs. Gustav Lindenthal and William R. Webster.

Having obtained some very interesting results, in connection with the preliminary experimental tests of carbon and nickel-steel built-up riveted eye-bars and forged nickel-steel eye-bars, and in the tests of the eye-bars used in the Blackwell's Island Bridge, it seemed to the writer that it would be desirable to give a summary of this work, and to place on file in the Library of the Society, a report, with tests, etc., where it would be accessible to those interested.

The eye-bars used in the structure were the largest ever manufactured, some of them being 16 by 2⅛ in., with heads 37½ in. in diameter, with 16-in. pins, and more than 64 ft. from center to center of pin holes. Special machinery had to be made for upsetting and rolling the eye-bar heads, and a testing machine of 2 000 tons capacity had to be designed and built to break them.

Nickel steel had been used for years in forgings, with special heat treatment. The best results were obtained by oil-tempering and annealing. When it was proposed to use nickel steel for eye-bars, it

*Additional data on this subject are filed in the Library of the Society, where they may be examined by any one who is interested.

was apparent that the hot bars would be distorted in handling during the process of oil-tempering and annealing, and it became necessary to learn what results could be obtained by modifying the ordinary methods of annealing carbon-steel eye-bars.

The first nickel-steel eye-bars were manufactured by The American Bridge Company at Edge Moor, and were tested at Pencoyd, in 1902. There were twenty-one of these bars, 6, 8 and 10-in., of basic open-hearth steel containing 3.26% of nickel. Records of the tests of these bars are filed in the Library of the Society, and a summary is given in Table 1. The elastic limits were determined by the halt in the mercury column, in the usual way.

In February, 1903, the Commissioner of Bridges, of the City of New York, requested the writer to make a series of experimental tests of nickel-steel eye-bars, and prepare specifications for steel of different qualities required for the construction of the Blackwell's Island and Manhattan Bridges. Eight bars of basic open-hearth steel, containing 3.24% of nickel, were made and tested at Pencoyd. Records of these tests, with the specifications prepared at that time, are filed in the Library of the Society, and a summary is given in Table 2. The elastic limits of this lot of eye-bars were taken by scribe marks of a finely pointed beam compass on a base length of 10 ft. A summary of the specification referred to above, and all other specifications referred to in this paper, are given in Table 3.

When submitting these specifications the writer stated:

"In preparing these specifications all the tests that had been made at Pencoyd, and other information at hand, were considered. The requirements may seem a little severe, but if proper care is taken in the manufacture of the steel, can all be met.

"In order to insure greater care in the manufacture and uniformity in the steel, high and low limits are specified for ultimate strength in all cases. The leeway of 15 000 lb. seems to be wide enough, and should not have to be increased. If the upper limit is omitted, the same amount of care will not be exercised in rolling the steel, very little attention will be paid to the finishing temperature, higher carbons will probably be used, and reliance will be placed on the results of the annealed test pieces to accept the steel.

"Tension and bending tests are called for on the bars as rolled without annealing. These are additional checks, to insure proper care being taken in the manufacture, and prevent brittle steel being used. If this is not done, and annealed test pieces are relied on alone to

TABLE 1.—Comparison of Specimen Tests of Nickel-Steel Bars, Unannealed and Annealed, with Eye-Bar Tests.

Bars manufactured by Carnegie Steel Co.
Eye-bars manufactured and tested by American Bridge Co.

All from Heat No. 10450
Analysis: C. 0.21, P. 0.007, S. 0.016, Mn. 0.53, Si. 0.011, Ni. 3.265.

Nickel Steel.		Specimen Tests.				Full-Sized Eye-Bar Tests.				Fracture.
		Unannealed.		Annealed.						
Mark of Bar.	Size of Bar.	Elastic limit.	Ultimate strength.	Elastic limit.	Ultimate strength.	Elastic limit.	Ultimate strength.	Percentage of elongation in 10 ft.	Percentage of reduction.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
A 1 *x*	6 by 1 in.	47 815	79 510	49 120	77 140	46 230	74 450	13.2	42.40	Silky, Angular.
A 2 *x*	"	48 190	80 300	50 895	75 890	46 300	74 100	16.2	49.80	" ½ Cup.
A 3 *x*	"	47 330	79 960	47 127	73 320	43 100	69 000	17.7	49.60	" " "
A 4 *x*	"	50 655	79 300	44 460	72 760	45 510	70 420	16.2	54.80	" " "
B 1 *x*	6 by 2 in.	46 963	76 930	48 945	76 920	47 300	72 200	16.3	42.90	" Cup.
B 2 *x*	"	46 615	78 880	18 105	78 260	46 260	74 290	17.1	46.90	" "
B 3 *x*	"	48 220	75 840	47 365	70 060	44 040	68 200	15.3	53.10	" ½ Cup.
B 4 *x*	"	50 335	78 420	48 515	74 170	43 120	69 340	12.7	41.23	" Angular.
B 5 *x*	"	48 215	76 360	51 663	78 790	44 860	72 400	12.1	41.10	" "
C 1 *x*	8 by 1½ in.	.....	.....	45 805	78 190	42 500	73 600	17.1	41.20	" "
C 2 *x*	"	47 813	76 970	47 730	70 240	40 420	66 150	20.8	57.50	" ½ Cup.
C 3 *x*	"	48 410	79 260	48 620	78 480	43 510	74 720	14.5	51.46	" Cup.
C 4 *x*	"	46 630	77 710	48 005	74 620	48 220	77 080	18.3	48.01	" "
C 5 *x*	"	47 460	79 170	48 650	74 090	41 450	74 450	16.8	47.44	" ½ Cup.
C 6 *x*	"	48 590	79 730	47 140	73 740	43 730	73 620	17.1	49.69	" Angular.
E 1 *x*	10 by 1¼ in	47 840	79 110	48 740	79 240	46 320	72 920	13.7	47.00	" Cup.
E 2 *x*	"	48 650	79 660	48 220	73 440	41 630	69 810	15.3	38.40	" Angular.
E 3 *x*	"	47 130	74 270	48 170	78 110	46 480	76 540	15.5	42.20	" Cup.
E 4 *x*	"	50 020	78 930	47 210	77 380	46 070	74 540	13.1	43.70	" "
E 5 *x*	"	48 320	80 320	47 970	75 710	42 960	73 290	17.1	51.70	" "
E 6 *x*	"	47 620	79 630	48 110	78 070	44 530	75 410	15.1	40.00	" Angular.

Elastic limit of specimen tests taken by drop of beam; of full-sized eye-bar tests, by halt in gauge. The figures in Columns 5 and 6 are the results of specimen tests of annealed bars.

TABLE 2.—Comparison of Specimen Tests of Nickel-Steel Bars, Unannealed and Annealed, with Eye-Bar Tests.

Bars manufactured by Carnegie Steel Co.
Eye-bars manufactured and tested at Pencoyd.

All from the same heat.
Analysis: C. 0.35, S. 0.022, Phos. 0.02, Mn. 0.68, Ni. 3.24.
Philadelphia, April 4th, 1903.

Nickel Steel.		Specimen Tests.				Full-Sized Eye-Bar Tests.				Fracture.
		Unannealed.		Annealed.						
Mark of Bar.	Size of bar.	Elastic limit.	Ultimate strength.	Elastic limit.	Ultimate strength.	Elastic limit.	Ultimate strength.	Percentage of Elongation in 18 ft.	Percentage of Reduction.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
$H\,1\,x$	6 by 2 in.	52 800	90 650	47 040	79 610	47 820	85 000	9.17	42.47	Silky, ¼ Cup, 5% Crystalline.
"	"	51 020	88 370	49 320	76 900					
$H\,2\,x$	6 by 2 in.	50 740	101 000	48 190	88 600	46 350	83 780	10.76	52.17	Silky, ½ Cup.
"	"	45 190	98 600	47 620	86 050					
$H\,3\,x$	6 by 2 in.	30 300	98 610	49 090	86 600	48 580	87 190	9.77	38.80	40% Crystalline, Irregular.
"	"	54 250	102 600	47 990	91 450					
$H\,4\,x$	6 by 2 in.	45 690	106 290	48 670	86 600	48 230	86 130	9.50	41.90	¾ Cup, 25% Crystalline.
"	"	49 780	101 920	48 360	88 860					
$H\,5\,x$	6 by 2 in.	49 960	102 460	51 760	90 260	48 380	86 490	9.50	44.20	Irregular, 30% Crystalline.
"	"	51 280	99 400	50 520	86 750					
$J\,1\,x$	6 by 1½ in.	49 950	95 150	46 240	83 140	49 350	86 240	10.44	45.75	Cup, 15% Crystalline.
"	"	50 520	103 420	44 800	86 780					
$J\,2\,x$	6 by 1½ in.	49 080	96 400	47 110	80 000	49 300	85 490	10.27	44.00	½ Cup, Crystalline, Specks on both edges.
"	"	49 450	99 670	43 180	98 800					
$J\,3\,x$	6 by 1½ in.	49 190	91 780	44 150	83 810	49 360	86 160	8.44	42.74	¾ Cup, 10% Crystalline on one edge.
"	"	53 390	111 120	44 780	83 600					

Elastic limits taken with dividers; 8-in. gauge length specimens; 10-ft. eye-bars.
The figures in Columns 5 and 6 are the results of specimen tests of annealed bars.

check the quality of the material, there is nothing to insure the finished eye-bars being annealed in the same manner and similarly restored. Whereas, starting with a known good material, the annealing will further improve it."

These specifications for nickel-steel eye-bars were submitted to the Board of Engineers, consisting of Messrs. Theodore Cooper, Henry W. Hodge, Mansfield Merriman, George S. Morison, and C. C. Schneider, Members, Am. Soc. C. E., appointed to consider an eye-bar cable for the Manhattan Bridge.

They reported that a nickel-steel forged eye-bar cable, made to these specifications, would be satisfactory to them, except that they considered the elastic limit of 50 000 lb. per sq. in. a little too high, and suggested modifying it to 48 000 lb.; also, that any visible set in the eye-bar should be taken as the elastic limit, using the best means to determine what constituted a visible set—a magnifying glass if necessary.

These specifications were used when the city first asked for bids on the Blackwell's Island Bridge, but the contract was not awarded at that time.

One of the manufacturers questioned the narrow leeway of 15 000 lb., on account of the influence of segregation on the ultimate strength in as large an ingot as would be required to roll the heavy bars. In order to determine what differences would be found, he rolled two bars, from two heats of nickel steel, 18 by 2 in. and 18 by 2¼ in., each more than 65 ft. long. Tests were taken from each end of these bars to represent the top and bottom of the ingots, with the following results:

18 by 2-in. plate	test cut from	top,	96 940 lb. tensile.
.....	" " "	bottom,	89 000 " "
18 by 2¼-in. plate	" " "	top,	82 040 " "
.....	" " "	bottom,	80 750 " "

These results were so satisfactory that he agreed that the leeway of 15 000 lb. was sufficient.*

When the city asked for bids the second time, the specifications were changed materially, and a minimum limit of 100 000 lb. tensile, with no maximum limit, was specified.

*A copy of all tests is filed in the Library of the Society.

TABLE 3.—Summary of Specifica-

Specifications.	Unannealed Specimens.					Annealed	
	Ultimate strength.	Elastic limit.	Percentage of elongation in 8 in.	Percentage of reduction.	Bends.	Ultimate strength.	Elastic limit.
William R. Webster's original specifications	90 000 to 105 000	55 000	18	35	180° 37′	85 000 min.	52 000
Blackwell's Island Bridge original printed specifications	90 000 to 105 000	52 000	do.	do.	do.	85 000 to 100 000	50 000
Blackwell's Island Bridge contract specifications	100 000 min.	55 000	$\frac{1\,600\,000}{\text{ultimate.}}$	to be recorded.	do.	85 000 min.	48 000
Modifications:* Lot or item tests	95 000 to 110 000	do.	do.	do.	do.	do.	do.
Test each heat with high tensile strength	113 000 min.	do.	do.	do.	do.	do.	do.
For bars which break in head	95 000 min.	do.	do.	do.	do.	do.	do.
Conclusions: Requirements that can be met as proven by tests of bars for structure.	95 000 to 110 000	do.	do.	35	do.	90 000 min.	52 000

* Tensile in full-sized tests reduced from 85 000 lb. down to 80 000 lb., all other requirements to remain as specified.

Where only one amount is given it means minimum.

After the contract for the bridge had been awarded, it was suggested to use built-up riveted eye-bars in place of the forged eye-bars called for in the contract. The writer, having been appointed Inspecting Engineer, was instructed to make a large series of tests, on bars of this kind, of both high-carbon steel and nickel steel, in order to determine their relative merits.

There were tested twenty-two high-carbon steel (80 000 to 90 000 lb. tensile strength) built-up riveted eye-bars, of the following dimensions:

8	eye-bars,	24	by	1	in.,	with	8-in.	pins.
4	"	24	"	$1\frac{1}{8}$	"	"	8 "	"
2	"	24	"	$\frac{3}{4}$	"	"	8 "	"
2	"	31	"	$\frac{3}{4}$	"	"	12 "	"
6	"	32	"	$\frac{3}{4}$	"	"	12 "	"

TIONS FOR NICKEL-STEEL EYE-BARS.

Specimens.			Full-Sized Eye-Bars.					Chemistry.			
Percentage of elongation in 8 in.	Percentage of reduction.	Bends.	Ultimate strength.	Elastic limit.	Percentage of elongation in 18 ft.	Percentage of reduction.	Location of fracture.	Phos.		S.	Ni.
								Acid.	Basic.		
20	40	180° 2T.	85 000	50 000	9	40	In body.	0.06	0.04	0.05	3.25 to 3.50
20	40	do.	do.	48 000	do.	40	do.	do.	do.	do.	3.50
1 600 000 ultimate.	to be recorded.	do.	do.	do.	do.	to be recorded.	do.	do.	do.	do.	do.
do.	do.	do.	85 000 and 80 000	do.	do.	do.	do.	do.	do.	do.	do.
do.	do.	do.	85 000	do.	do.	do.	do.	do.	do.	do.	do.
do.	do.	do.	do.	51 000	6	do.	In head.	do.	do.	do.	do.
1 800 000 ultimate.	40	do.	do.	50 000	9	35	In body.	do.	do.	do.	do.

All bending tests are full thickness, and not less than 4 in. wide.
Elastic limits of full-sized tests to be taken by extensometer on base length of 10 ft., a permanent set of 0.025 in. to be considered the elastic limit.

and twenty-five nickel-steel (84 000 to 96 000 lb. tensile strength) built-up riveted eye-bars of the following dimensions:

8 eye-bars, 24 by 1 in., with 8-in. pins.
10 " 24 " $\frac{3}{4}$ " " 8 " "
7 " 32 " $\frac{3}{4}$ " " 12 " "

All the riveted bars had one pin-plate on each side, and the rivets were countersunk. All holes were drilled from the solid, and all sheared edges planed; most of the bars had two lines of $\frac{15}{16}$-in. drilled holes along the body. The center-to-center distances of pin holes were 23 ft. 6 in. and 25 ft.*

From six to eight tension and bending tests were made on specimens from each plate, of both high-carbon and nickel steel, used in these

*Fully detailed drawings of these bars have been filed in the Library of the Society.

built-up eye-bars. Special care was taken in the heating and rolling of these steels.*

In order to determine the elastic limits as accurately as possible, the writer had a special extensometer made. It multiplied ten times, could be relied on to about 0.005 in., and was easily attached to the bar. Fig. 1 shows this instrument and the method of using it.

None of the riveted eye-bars gave satisfactory results, as shown by the detailed reports of the tests.† The loss of strength in the carbon-steel bars, from the average of the specimen tests, was from 11 to 41% on the net area, and from 20 to 46% on the gross area; and, in the nickel-steel bars, from 7 to 13% on the net area, and from 13 to 22% on the gross area.‡

This loss of strength was greater than would be expected from the results of tension tests on small riveted joints or on small narrow bars with drilled holes in them, and is no doubt due to the wide thin plate tearing when tested in tension. Particular attention is called to this, as it has often been suggested to make very large eye-bars from wide plates by machining them narrower in the center in order to prevent the loss of strength which occurs in forged eye-bars due to annealing. Before large bars of this kind are used, a complete series of tests should be made, in order to show what the actual loss in strength would be in a wide, thin plate, as compared with a forged eye-bar of half its width and double its thickness made from steel showing the same tensile strength in the specimen tests.

Fig. 2 illustrates an end of one of the 24-in. riveted bars, and shows the transmission of the strains by the rivets, as indicated by the cracking of the mill scale on the pin-plates, in a remarkably uniform manner.

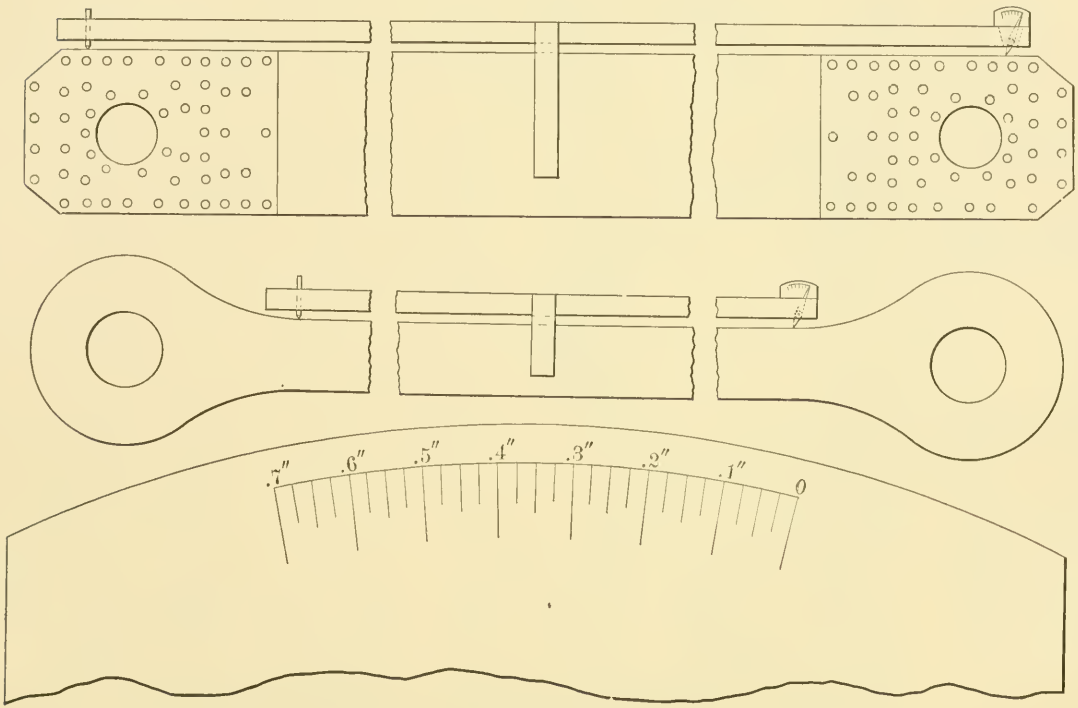
All the riveted carbon-steel eye-bars broke off square, with granular fracture, little or no reduction of area, and elongations from 0.06 to 3.21% in the body of the bar. The nickel-steel riveted eye-bars, made of the softer heat of steel, containing 0.30% of carbon and 3.72% of nickel, broke with from 50 to 85% granular fractures, small reductions of area, and elongations from 2.17 to 3.11% in the body of the

*A report of these tests, together with a diagram showing the location of the test pieces in the plate, is filed in the Library of the Society.

†Filed in the Library of the Society.

‡Full details of all tests, with extensometer readings, have been filed in the Library of the Society.

EXTENSOMETER, AS USED ON RIVETED AND FORGED EYE-BARS.



Full Sized Detail

FIG. 1.

bar; and all the harder steels, containing 0.477% of carbon and 3.56% of nickel, and 0.424% of carbon and 3.57% of nickel, broke off square, with granular fractures, little or no reductions of area, and elongations from 0.78 to 2.39% in the body of the bar.*

Before these full-sized tests were completed, instructions were issued to the writer to make tests on nickel-steel forged eye-bars and to report on which bars he considered best suited for the structure. Twelve 14 by 2-in. bars, and six 16 by 2-in. bars were tested. Half of these bars were of acid open-hearth steel containing 0.33% of carbon and 3.72% of nickel; and half of basic open-hearth steel containing 0.36% of carbon and 3.40% of nickel. The same care was exercised in rolling these bars as in rolling the former bars. The eye-bars were all forged by The American Bridge Company, at Ambridge, Pa., and were tested at the works of The Phœnix Iron Company, Phœnixville, Pa., but some of the larger bars could not be broken, as they were beyond the capacity of the machine.

Tension and bending tests were made from each end of each bar rolled.†

The writer reported on the results of all the tests made, advising the use of forged nickel-steel eye-bars.‡

Table *A*‡ gives a summary of the results of all tests made on nickel-steel bars; the comparisons there given are between the net sections of the riveted bars and the forged bars. Table *B*‡ gives the comparison between the gross section and the forged bars. For comparison, the average results of the specimen tests are given in each case.

Before any work was started on rolling the flats or forging the eye-bars for the structure, the following full-sized tests were called for, in order to test the uniformity of the material, methods of manufacture, and whether the upset head would develop the full strength of the bar:

Four heats of steel to be rolled:

3 full-sized eye-bars to be tested from the first heat,
3 " " " " " " " second heat,
2 " " " " " " " third heat,
2 " " " " " " " fourth heat.

*A blue-print and a report, giving the location and character of the fractures, is filed in the Library of the Society.

†Full details of all specimen tests and full-sized tests, showing extensometer readings, are filed in the Library of the Society.

‡Filed in the Library of the Society.

24″ x 1″ Bar with two Pin-Plates 24″ x ½″. Test reported June 30th, 1904.
FIG. 2.

Owing to the delay in completing the upsetting machine and the testing machine, however, about 2 000 tons of nickel-steel flats for eye-bars were rolled before these preliminary tests were made. As the contract specifications did not give any upper limit in tensile strength, the 2 000 tons of flats really consisted of two grades of steel, as the ultimate strengths in the sample tests ranged from 100 000 to as high as 126 000 lb. per sq. in.

The results of the ten full-sized tests of eye-bars from the first four heats were so irregular that they were considered experimental tests, and the manufacturer decided to test all the eye-bars which had been forged up to that time. These bars were annealed under varying conditions, using a pyrometer to determine the annealing temperatures, and were tested to destruction. Additional bars were also forged, annealed, and tested by the manufacturer before any eye-bars were submitted for test and inspection for the structure. In all, there were seventy-three of such bars tested.

In this preliminary work it was found that the results of tests on full-sized eye-bars, made from heats of steel of more than 115 000 lb. per sq. in. tensile in the sample, were so irregular that it was decided to make a full-sized test on an eye-bar from each of such heats of the 2 000 tons already rolled, and on all steel to be rolled, to make a full-sized test on each heat of more than 110 000 lb. per sq. in. tensile in the sample test, if the annealed sample test showed more than 100 000 lb. per sq. in.

As the work progressed, the following additional modifications were found advisable, in order to secure satisfactory eye-bars for the structure and prevent the use of brittle steel:*

Ultimate strength in unannealed specimen tests reduced to 95 000 lb. per sq. in.; all other provisions to stand as specified.

Ultimate strength in full-sized tests reduced from 85 000 to 80 000 lb. per sq. in.; all other provisions to stand as specified.

Eye-bars of heats of from 95 000 to 110 000 lb. per sq. in. in the unannealed specimen to be tested by lots or items, and 3% of such bars to be tested.

Test by heats all eye-bars made of steel of 113 000 lb. per sq. in. tensile, and over, if the annealed specimen test is over 100 000 lb.

Test by heats all eye-bars made of steel of 111 000 to 113 000 lb. per sq. in. tensile in the specimen test when carbon and manganese are very high and the annealed specimen test is over 100 000 lb.

*A report on these preliminary tests of 16-in. bars, and modifications desired, is filed in the Library of the Society.

Desired: Carbon not over 0.40, if manganese is 0.80 or over.
Desired: Carbon not over 0.45, if manganese is 0.70 or over.

In all the preliminary experimental eye-bars and those for the structure, the elastic limits were taken by the extensometer. Tests of eye-bars for the structure were made. The extensometer readings,* are grouped as follows:

Bars that met the requirements of the specifications;
†Bars that broke in the head, but were accepted under a modification of the specifications;
Bars that failed in elastic limit;
Bars from special high heats which broke in the head, with low elongation.

For comparison, some tests of carbon-steel eye-bars, showing the extensometer readings, are also filed in the Library of the Society.

All the nickel-steel eye-bars were tested on The American Bridge Company's large testing machine at their Ambridge Plant. The results on this machine are a little lower than those on the Government machine at the Watertown Arsenal.‡

The clause in the printed specification covering the annealing of eye-bars was not satisfactory for nickel steel, and the manufacturer determined the proper annealing temperature in the series of full-sized eye-bar tests referred to—the ten tests from the first four heats and the other full-sized tests made at that time. The pyrometer was used to determine temperatures in annealing all bars for the structure.

The bending tests on the bars showed that the wide full-thickness bends on unannealed specimens (180° $3T$) are a good check on the methods of rolling, and the full-sized bends of the pieces annealed with the eye-bars, a good check on the annealing.

The results of all the tests prove conclusively that a nickel steel of from 95 000 to 110 000 lb. per sq. in., tensile, in the unannealed specimen, and of 90 000 lb. per sq. in., minimum tensile, in the annealed specimen, would give eye-bars with a minimum elastic limit of 50 000 lb. per sq. in. in full-sized test and guard against brittle steel. The desired ultimate for full-sized tests was 90 000 lb. per sq. in., but 85 000 lb. would be accepted provided the eye-bars would show a minimum elastic limit of 50 000 lb. per sq. in.

*Filed in the Library of the Society.

†The Commissioner of Bridges modified the specifications, so that bars which broke in the head but developed an elastic limit of 51 000 lb. and an ultimate strength of 85 000 lb., with stretch of 6% in 18 ft., would be accepted.

‡The report of the standardization of the Ambridge machine is filed in the Library of the Society.

DISCUSSION.

Mr. Lindenthal.

GUSTAV LINDENTHAL, M. AM. SOC. C. E. (by letter).—The writer desires to add some historical information to this paper.

The use of large nickel-steel eye-bars in the construction of the Blackwell's Island Bridge, New York City, originated with the writer when he was Commissioner of Bridges (1902-03).

The cross-sections of the tension members were so large that the use of higher steel for them appeared expedient. Certain tests of nickel-steel eye-bars, 6 to 10 in. wide, made at Pencoyd in 1902, showed that a material some 50% stronger than the usual structural steel, and perfectly reliable for forged work, could be obtained.

At first, eye-bars 18 in. wide and from 2 to 2½ in. thick were intended. The existing eye-bar plants could make bars only up to 16 in., but the large tonnage (17 000 tons) contemplated in the Blackwell's Island cantilever structure and in the chain design for the Manhattan Bridge would have justified the erection of a larger plant for the heavier bars.

The writer was not able to obtain the necessary appropriation for both bridges, but only for the Blackwell's Island Bridge. Because of the smaller tonnage to be contracted for, the largest eye-bars were limited to 16 in., the capacity of the existing plant.

The attempts, mentioned by Mr. Webster, of substituting riveted eye-bars for the forged nickel-steel eye-bars, were made after the writer had relinquished charge of the work; so also other changes in the design which resulted in the weak structure, which, from the official investigation and reports made after its completion, Blackwell's Island Bridge (now called Queensboro Bridge) is known to be.

Mr. Webster.

WILLIAM R. WEBSTER, M. AM. SOC. C. E. (by letter).—The writer has nothing to add to the discussion of the paper, except the following statement, which should have been incorporated in the paper when originally written: Mr. Gustav Lindenthal, Commissioner of Bridges, and Chief Engineer, City of New York, was the first engineer in the United States to suggest the use of nickel-steel eye-bars for long-span bridges. At his request the American Bridge Company took up the matter; the International Nickel Company contributed the nickel; the Carnegie Steel Company made the steel and rolled the bars; and the American Bridge Company upset, forged, and tested the eye-bars.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1111

THE MAXIMUM WEIGHTS OF SLOW FREIGHT TRAINS.*

By C. S. Bissell, M. Am. Soc. C. E.

With Discussion by Messrs. L. A. Riley, 2d, and C. S. Bissell.

It is hardly necessary to mention the great and growing importance of the subject of train weights. Study of the problem has given rise to many different forms of investigation which are constantly appearing in the railroad journals and which are indicative of greater refinement in the making up of trains in the future. Most writers have endeavored to treat the subject in its entirety, comprehending the operation of both slow and fast trains, whereas the object of this paper is to present only the case of slow freight trains, and to outline briefly the history of the various steps which led to the conclusions finally reached.

The writer was called upon to formulate some method of estimating operating expenses, over proposed revisions or projected lines not constructed, such as would permit of the intelligent comparison of expenses on two or more projects or routes of haul. The locomotive was of a type weighing, with its tender, 168 tons, of which 173 000 lb. rested on the driving wheels; and the train was to consist of cars weighing 20 tons each when empty, with a capacity of 50 tons. The

* Presented at the meeting of April 21st, 1909.

speed was not to exceed 10 miles per hour on ruling grades, and no benefit derived from momentum was to be considered in fixing the train weight. The resistance due to curvature was to be allowed for by compensating the ruling grades at 0.05% per degree of curve.

The first principle of train resistance, namely, that a given train weight confined in a few cars requires less tractive power to move it than the same weight composed of many empty cars, led the writer to a form of equation involving the relation between the dead weight and the lading of the cars, which is evidently the same as if the average car weight or the actual number of cars had been used.

The tractive power of the locomotive was determined as the average amount which would usually be developed within the adhesive power of the driving wheels, considering that atmospheric conditions and steaming qualities remained practically constant at normal values. The tractive power was to be reduced by the proper amount for a constant speed of 10 miles per hour.

With these ideas, which indicated the general form of the equation, the paper* on "Virtual Grades for Freight Trains" by A. C. Dennis, M. Am. Soc. C. E., was consulted, with the result that the train resistance was taken at 4 lb. per ton of train weight for full cars and 9 lb. per ton for empty cars. Also, from this paper, was taken the reduction of 13.7% in the tractive power for the speed of 10 miles per hour.

The hauls in Table 1 are from the records of The Pennsylvania Railroad Company, and represent a fair average of actual train weight for one locomotive of the type described, for a speed of 10 miles per hour.

TABLE 1.

Compensated grade. Percentage.	Gross train weight, in tons.
0.300	3 292
0.655	1 898
1.055	1 238
1.260	953
2.130	555

Using the values in Table 1, and increasing the train capacity 10% for overload, as a limiting maximum, the coefficient of tractive

* *Transactions*, Am. Soc. C. E., Vol. L, p. 1.

power was established as 0.232; and the complete expression for tractive power then became 0.232 $\times$ 0.863 $\times$ the number of pounds on the drivers, or 0.2 $\times$ the number of pounds on the drivers, in which the 0.863 is the complement of 13.7 per cent. Introducing now the factor for train resistance, and denoting the ruling grade percentage by g, the general equation is obtained:

$$\left.\begin{matrix}\text{Tons of}\\ \text{train weight}\\ \text{behind tender.}\end{matrix}\right\} = \frac{0.2 \times \text{pounds on drivers.}}{9 - 5\,\dfrac{\text{Weight loaded on train.}}{1.1 \times \text{Capacity of train.}} + 20\,g} - \left\{\begin{matrix}\text{Tons of}\\ \text{locomotive}\\ \text{and tender.}\end{matrix}\right\} \quad . . (1)$$

in which the "Capacity of train" is the sum of the capacities of the cars, and all tons are of 2 000 lb. For the particular case in hand, the weight on drivers is 173 000 lb., and the weight of locomotive and tender is 168 tons; hence, with cars of any class loaded to the maximum, the equation assumes the special form:

$$\text{Net tons behind tender} = \frac{34\,600}{4 + 20\,g} - 168.$$

Using this equation and the values of g for the hauls given above, from which the coefficient of tractive power was derived, it is found to give the train weights within about the weight of one empty car, except in the case of the fourth haul, which it makes 64 tons too high; but, as the last haul is only 19 tons too high, it is reasonable to assume that the equation represents safe values in the case of this example. Also, it is reasonable to assume that since for empty cars the train resistance is 9 lb. per ton of train weight, the values intermediate between 4 and 9 lb. per ton will be given correctly by the equation for all partial ladings of the train. It will be noted that for a train of empty cars the equation becomes:

$$\text{Net tons behind tender} = \frac{34\,600}{9 + 20\,g} - 168.$$

Because the purposes for which this equation was derived are usually expressed in terms involving an annual paying tonnage to be moved, the form of the general equation is believed to present special advantages, and from it a table may be formed showing the tons of lading and the number of cars in the train, which is convenient in estimating operating expenses; and the possibility of using it in making up trains is also evident.

The equation has thus far fulfilled the requirements for which it was designed, but suggestions have been made which show that it can be greatly improved in point of accuracy of form and adaptability in making up trains.

One objection to the form is found in the fact that the car resistance per ton varies in a straight line, or, in other words, that it is proportional to a constant increment of lading. Every indication in Nature goes to prove that probably the variation should be in proportion to an increment of lading which is constantly increasing, or to a decrement of similar character; in short, it should represent a curve instead of a straight line when depicted graphically. The grade resistance, 20 g, is evidently mathematically correct, being a simple case of a weight on an inclined plane; but the further suggestion of reducing the value of the tractive power for the grade involved with the dead weight of locomotive, tender, and caboose, has a great advantage in point of accuracy over the method of simply subtracting such dead weight as indicated in the above equation, particularly in cases where the tractive power is determined by a dynamometer car. For general use, it seems advisable to express the relation of the train weight to the number of cars as the average total car weight. It can readily be seen that if the four axles and eight wheels of an ordinary car are identical in size and weight, then the total weight of the train divided by the number of cars is an average car weight, which is a true measure of the resistance per car. If the condition is not realized absolutely, the average car weight will be affected by an inconsiderable amount in the case of an ordinary mixed train.

In view of these considerations, the equation must necessarily be expressed in a form somewhat different from that given above, and, for this purpose, the writer makes use of the following values, which are selected from a number of tests made with a dynamometer car, in which R is the resistance of a train, in pounds per car, and W is the average weight per car, in tons of 2 000 lb., for a speed of 10 miles per hour:

TABLE 2.

Point.	R (pounds).	W (tons).
A	160	20
x	195.7	40.2
y	199.0	42.8
B	216.0	72

Referring to Fig. 1, upon which the points, A and B, are located, it is clear that the resistance per car will decrease from B to A, and will become zero when the number of cars becomes zero. Hence the line of variation must pass from B through A and through the origin

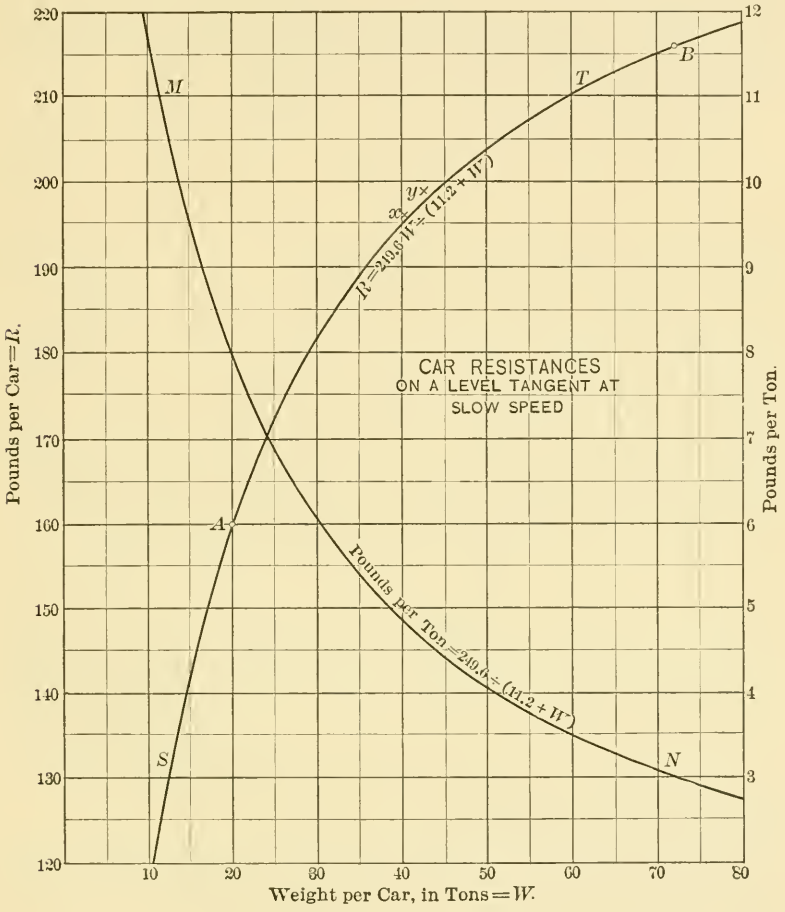


FIG. 1.

of co-ordinates, zero. It must, therefore, be a curve; and such a curve is represented by the equation:

$$R = \frac{a\ W}{b + W},$$

its particular form for this case being,

$$R = \frac{249.6\ W}{11.2 + W},$$

which is the line, $S\ T$, in Fig. 1. Plotting the points, x and y, it is seen that they agree closely with the values given by the equation, thus confirming the assumption that the resistance per car varies as a curved line of this character.

Dividing the values of R by the corresponding values of W, and plotting the results to the scale on the right of Fig. 1, develops the curve, $M\ N$, of pounds per ton of train weight.

It is now possible to formulate the equation:

$$\text{Tons of train weight behind tender} = \frac{P - 20\ g\ m}{\frac{a}{b + W} + 20\ g} \quad \ldots\ldots\ldots (2)$$

in which P = the pounds of tractive power at the drawbar; m = the weight, in tons, of the locomotive and tender; a and b are constants; W is the average weight per car, in tons; and g is the grade, in percentage. The tractive power, P, is here reduced by 20 g m (where the weight of a caboose may be included in m if desired), instead of subtracting the dead weight, m, after the division has been made. Substituting the known terms taken from Tables 1 and 2 and those derived for Fig. 1, an average value of P is found to be 32 100 lb., and therefore the equation for train weight for this particular case becomes:

$$\text{Tons of train weight behind tender} = \frac{32\ 100 - 3\ 360\ g}{\frac{249.6}{11.2 + W} + 20\ g}.$$

This equation does not agree with the values in Table 1 as closely as do the results from Equation 1, but it is more rational in form, and is adapted to use in connection with records taken with a dynamometer car, from which the tractive power, P, and the constants, a and b, can be readily determined by experimental trials for any particular forms of locomotives or cars.

For the purpose of making up trains, an equation similar to the above can be expanded into a table. Thus, for any particular division of the railroad, the ruling grade, g, is known; assuming it to be 0.5%, for example, the equation becomes:

$$\text{Tons of train weight} = \frac{30\ 420}{\frac{249.6}{11.2 + W} + 10}.$$

From this may be prepared for all car weights a form similar to Table 3, which shows only three values of average car weight. The

reduction for temperature, of course, must be determined by past experience. A similar table, prepared for each class of locomotive on the division, can be used for making up trains by a yard-master of very mediocre intelligence. The process of taking the continued sum of the car weights until the total indicated in the table is approximately reached, and then dividing the result by the number of cars to obtain the average car weight, is a simple one. The difference of a few cars more or less is then made up, and the total train weight of the completed train is finally checked by a repetition of the process.

TABLE 3.

Average car weight, in tons.	M. & N. Division—Locomotive Class H.				
	Train Weights for Various Temperatures.				
	Summer.	45° — 25°	25° — 5°	Below 5°	Emergency.
40	2 046	1 840	1 636	1 535	1 023
41	2 058	1 852	1 646	1 544	1 029
42	2 071	1 864	1 657	1 553	1 036

This example of the manner in which trains may be made up is given to illustrate the practicability of dispensing with a "car factor," consisting of a predetermined number of tons to be added to each car in the train. Such a car factor is in reality a fictitious weight, and its use introduces the element of a "straight-line variation" in reaching the final result, which is questionable in point of accuracy. The following quotation is taken from "Tonnage Rating," an article by Mr. F. W. Thomas*:

Mr. Thomas says:

"The most difficult problem after the rating has been ascertained and proven, is to express the rating intelligently and in such a form that the dispatchers, yard-masters, foremen or switch crews and conductors can understand and easily interpret the rating sheets.

"The most difficult thing to impress upon those interested is the fact that the rating is often governed by the number of cars in the train; the greater the number of cars, the greater the rolling resistance. In the eyes of the average train master and dispatcher a thousand tons, whether confined in twenty cars or in fifty, is a thousand tons."

* * * * * * *

* *American Engineer and Railroad Journal*, April, 1907.

"You will note * * * that the maximum rating is shown in cars weighing fifty tons, and for every car added to the train above this given number of cars a reduction from the maximum rating must be made of from four to five tons. * * * I cannot say that this reduction is based on any fixed rule, beyond, as mentioned above, that it is the fruit of long investigation and a series of tests * * * ."

The writer thinks that Mr. Thomas intended to say, in the instance above, "the greater the number of cars the greater the rolling resistance per ton of train weight," which is usually difficult to make clear.

As a matter of fact, the determination of the car factor is sometimes based on a "fixed rule," or rather a carefully wrought out series of experimental tests put into a rational mathematical form. This form usually is developed by equations, some of which represent straight lines, but whether or not this be true, the unfortunate fact remains that the use of such a car factor, when derived, constitutes a constant increment, thus introducing a form of straight-line variation into the calculation.

It may be asked, what objection can be made to such a variation, and in answer the writer appeals to the reason of those who are students of the problem here presented. Natural forces represented graphically, almost without exception, are forms of curves. The construction of a train is artificial, but the forces developed by the movement of the train are natural in their characteristics; and continued study brings with it the growing conviction that the graphics in this problem should be curves rather than straight lines. Granting this, the use of the car factor must be dispensed with, and a rigidly curvilinear method or equation must be formulated. If we conceive of a level railroad tangent as an arc of 4 000 miles radius, the center of which is the earth's center, then Equation 2, as given above, is strictly curvilinear in its components and in its entirety; but if this conception appears to violate the sense in which the quantity "20 g" is used, there still remains the argument that grade is an artificial and not a natural element of force in this problem.

The economic issues dependent upon a true determination of maximum train weights, especially for slow freight trains, are of such grave importance that the writer feels justified in stating that any criticisms or suggestions which will throw more light on the subject will be welcomed by the majority of railroad men.

The data upon which the foregoing developments are based are believed to represent normal conditions. They are the results of many tests, and of careful selection and reduction. In every case, however, they apply only to the slow speed of from 10 to 7 miles per hour. The equations are given to show only the form of variation, since it is apparent that the constants in them must be derived from experimental tests.

DISCUSSION.

Mr. Riley. L. A. Riley, 2d, Esq. (by letter).—A close analysis of Mr. Bissell's paper shows some disagreement with observed data, and the writer believes also with theory. The accuracy of Mr. Bissell's weights of trains on compensated grades is not questioned, but they appear to be somewhat low, considering the weight of the locomotive he uses for estimating purposes.

The writer's notebook is full of record hauls, but it is not thought that they would serve any useful purpose in this discussion. It might be interesting, however, to give (in Table 4) the tonnage rating of a consolidation-type, slow-freight locomotive, which rating has stood the test of more than a year's operation under all sorts of conditions.

The locomotive in question, as may be seen from Table 4, was considerably lighter than Mr. Bissell's.

That the majority of the figures in Table 4 were obtained in practice the writer can testify, and he can also testify to the fact that at such times no sand was used to increase the adhesion, which was calculated at 25% in making up the rating. The winter rating was for dry track, the only change in calculation being an increase of the rolling friction. In case of icy rails, or stormy weather, it was subject to a further reduction. All of which leads to a disagreement with the 20% adhesion and the theoretical deduction for the same, as given by Mr. Bissell. He states that "the tractive power was to be reduced by the proper amount for a constant speed of 10 miles per hour," and, later, that 13.7% was taken as the proper reduction in the tractive power for a speed of 10 miles per hour.

TABLE 4.—Fifty-Class Engines; Consolidation Type; Cylinders, 22 by 28 in.; Steam Pressure, 200 lb.; Total Weight, 144 tons; Weight on Drivers, 155 156 lb.

Grade.	Rating:	
	Summer.	Winter.
0.38%	2 850	2 485
0.5%	2 424	2 155
0.7%	1 940	1 940
1.0%	1 492	1 386
1.1%	1 386	1 292
1.2%	1 292	1 212
1.4%	1 140	1 078

Compensated actual grades. Speed, 12 miles per hour. Rolling friction, 6 and 8 lb. per ton, respectively. Track in fair condition.

It appears that he calculates the rate of adhesion as 23.2% from the tonnage records, and then reduces this rate by 13.7% for a speed

of 10 miles per hour. Sliding friction is subject to a reduction at increased speeds, but the writer does not know where Mr. Bissell finds authority for a reduction in the rate of adhesion with change in speed. Mr. Riley.

If the rate of adhesion is 23.2% at zero miles per hour, it remains practically the same at any speed. In other words, the tractive power of the locomotive will follow the adhesion from zero speed up to a critical speed at which the locomotive fails to supply steam in sufficient quantities to sustain this pull. This critical speed is different for almost every type and design of locomotive. Fig. 2 may illustrate the point.

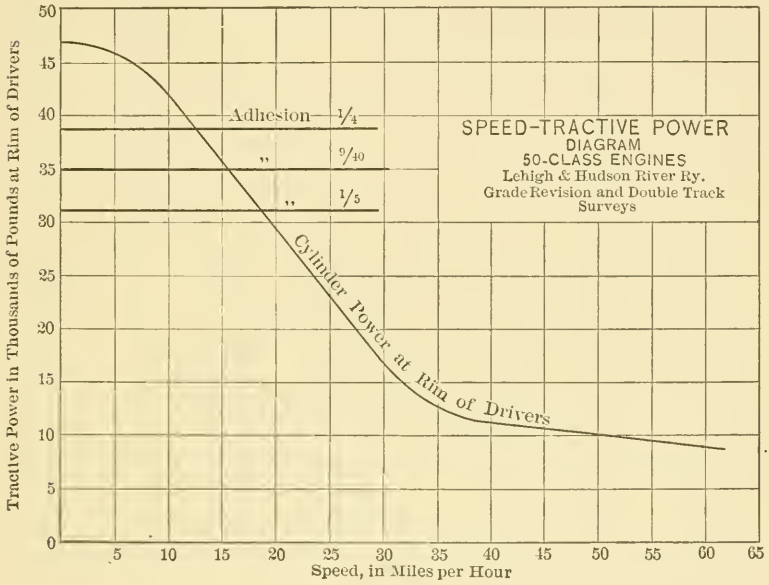


Fig. 2.

Under the best track conditions the locomotive referred to in Fig. 2 holds an even tractive power of 38 800 lb. up to the critical speed of 12½ miles per hour, at which point the capacity of the locomotive boiler reduces the tractive power with increased speed along the curve marked "Cylinder Power at Rim of Drivers."

In regard to freight-train resistances, Mr. Bissell's curve of decrease in resistance due to increase in lading is most interesting, and it would seem that more data might be of value in the matter.

On Fig. 3 the writer has plotted some values, as determined by dynamometer-car tests by Mr. D. C. Crawford in 1901 and by Mr. M. H. Wickhorst in 1904; also a formula proposed by Mr. G. R.

Mr. Riley. Henderson in his "Locomotive Operation," presumably from observed data. These tests were all stated to be for slow speeds and straight track. Mr. Crawford's and Mr. Wickhorst's figures check remarkably well, and would lead to the conclusion that Mr. Bissell's figures are rather high. Mr. Henderson's formula, however, gives values which come somewhat closer to Mr. Bissell's for heavy loads. The effect of temperature on this curve is not discussed; presumably the values are for conditions above the freezing point.

In Equation 2 the question of the definition of tractive power arises. Mr. Bissell calls P the tractive power at the drawbar. From a mathematical and exact point of view, the drawbar pull is a most unsatisfactory figure. The train may be considered as a single body on which a force is impressed, counterbalanced by certain resistances. The force impressed in this case happens to be applied by a steam engine mounted on what may be considered one car of this train, but if the engine had been mounted on a concrete base at the summit of the grade, and had exerted its tractive power by a cable, the principle would have been the same. If the engine mounted on the car and the one on the ground were of the same size, design, and steam pressure, the tractive power of each would be the same.

According to Mr. Bissell's formula, however, the tractive power of these two engines would be quite different. There are two balanced forces under consideration, the pull of the prime mover and the resistance of the body moved; the body moved is the total train, not the train back of the engine. The latter consideration will certainly lead to confusion in studying velocity grades. If the train is accelerated or retarded, the drawbar pull, as calculated by Mr. Bissell, is not affected by such acceleration or retardation; but it is obvious that the change in speed does affect the drawbar pull, as the mass of the engine and tender is either absorbing or giving up energy due to its change in momentum. The tractive power of the prime mover, however, is not affected by this change in speed, and the gain or loss in momentum takes its proper place with the other resistances of the body moved.

It has been advanced as an argument against "Cylinder Tractive Power" or "Tractive Power at Rim of Drivers," that an engine with a boiler pressure of 10 or 20 lb. could not move itself, and that it would be ridiculous to assume that it had any tractive power whatsoever. Nevertheless, that engine has just as real a tractive power as the engine which is stalled with its train on a grade. It has a tractive power even though that tractive power is not sufficient to move the mass to which it is applied. What would become of the drawbar pull, as determined in Mr. Bissell's formula, if an attempt were made to apply it to multiple-unit electric trains? One would be simply forced to consider the tractive power of the motors as applied at the wheels and not at the drawbar.

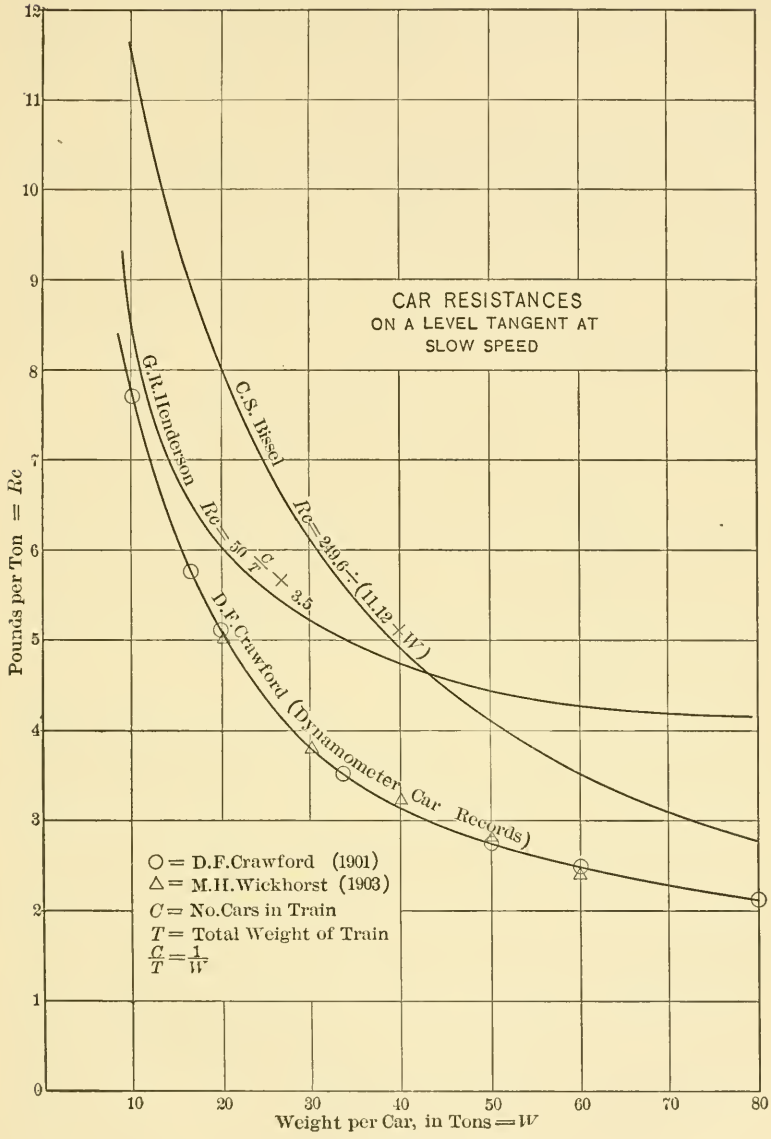

CAR RESISTANCES
ON A LEVEL TANGENT AT
SLOW SPEED
G.R.Henderson $Re = 30\frac{c}{T} + 3.5$
C.S. Bissel $Re = 249.6 \div (11.12 + W)$
D.F.Crawford (Dynamometer Car Records)
○ = D.F.Crawford (1901)
△ = M.H.Wickhorst (1903)
C = No.Cars in Train
T = Total Weight of Train
$\frac{C}{T} = \frac{1}{W}$
Pounds per Ton = Re
Weight per Car, in Tons = W
0
1
2
3
4
5
6
7
8
9
10
11
12
10
20
30
40
50
60
70
80

FIG. 3.

Mr. Riley. For these reasons it seems to be more logical to modify Mr. Bissell's Equation 2 in some such way as the following:

$$\text{Tons of train weight behind tender} = \frac{T - (20g + l)\, m}{\frac{a}{b + w} + 20g}$$

in which

T = Tractive power at rim of drivers,

l = Frictional resistances of locomotive wheels and trucks considered as a loaded car.

The other symbols are the same as Mr. Bissell proposes.

The relation between drawbar pull and tractive power is then as follows:

Drawbar pull, $P = T - (20g + l)\, m$ for constant speed and straight track;

or, to make the formula more universal:

$$P = T - \left[20g + c + l + \frac{1000\,(v_2^2 - v_1^2)}{dg}\right] m$$

in which

c = resistance due to curvature, in pounds per ton of engine weight,

v_1 = velocity, in feet per second, at beginning of period considered,

v_2 = velocity, in feet per second, at end of period considered,

d = distance, in feet, covered during period,

m = weight of engine, in tons,

g = acceleration of gravity.

It must be admitted, however, that even this is not exact, since it omits the consideration of the power absorbed or given up by the change in rotative speeds of the engine wheels. However, since it concerns itself only with the engine, it is believed that it is sufficiently exact for all grade-revision purposes excepting possibly the calculation of limiting momentum grades, in which case the methods adopted by Mr. J. B. Berry, in the Union Pacific grade-revision work, are recommended as most exact and logical. A detailed discussion of these methods may be found in the *Proceedings** of the American Railway Engineering and Maintenance-of-Way Association.

Mr. Bissell. C. S. Bissell, M. Am. Soc. C. E. (by letter).—It seems probable that Mr. Riley has misunderstood the means by which the coefficient, 0.2, in Equation 1, was reached. The value, 0.2, in conjunction with the resistances, $4 + 20\ g$, satisfies the values given in Table 1 within the limits mentioned by the writer; and, since the locomotive can surely exert more hauling power in starting than it does at a speed of 10 miles per hour, the question remains as to how much this difference is. The data of Mr. Dennis fix the proportion at 13.7%, and hence the factor,

* Vol. V.

0.232, is derived, since $0.232 \times 0.863 = 0.2$. The expression, "0.2 $\times$ pounds on drivers" is merly a measure of the pull necessary to move the locomotive, tender, and train at a speed of 10 miles per hour; and the distinction as to whether the reduction of 13.7% is made from the "tractive power" or from the "adhesion" is evidently unnecessary. Mr. Bissell.

This calls attention to the difference in car resistances, as expressed by the writer in Equations 1 and 2. The drawbar pull, T, in Equation 2, is the pull required to move only the train behind the tender, whereas the expression, "0.2 $\times$ pounds on drivers" is the power required to move the locomotive and tender, as well as the train. Therefore, the values of car resistance, 4 and 9, in Equation 1, are found to be about 3 and 8, in Equation 2, the resistances of the locomotive and tender being roughly proportional to the difference.

Mr. Riley's suggestion of changing the value of T, in Equation 2, to represent the "tractive power at rim of drivers," instead of the drawbar pull, is interesting, since it permits the use of a "cylinder tractive power" for those who prefer it to the drawbar pull. Taking this value of T, in Mr. Riley's suggested form, $T - (20\ g + l)\ m$ is the same value that the writer gets from the expression, $T - 20\ g\ m$, when T is the drawbar pull. The writer's use of T as the drawbar pull, instead of the "tractive power at rim of drivers" gives at once, from the test runs, the value of $T - l\ m$, as proposed by Mr. Riley. The latter's proposed form, however, would seem to the writer to be improved by placing the constant, $+ l$, or the expression, $+ l\ m$, in the denominator with the other resistances, instead of applying it as a reduction to the tractive power. It is notable here that, if the speed were changed, the "constant," l, would probably become a resistance varying with the speed in a curve.

Mr. Riley has referred to a "detailed discussion," in the *Proceedings* of the American Railway Engineering and Maintenance of Way Association, Vol. V, by Mr. J. B. Berry, of the Union Pacific Railroad. In this paper Mr. Berry says:

"* * * maximum adhesion should never be considered as more than 25 per cent. of weight on the drivers. This will seldom be developed except in starting and by using sand. Where rail is dry adhesion can be safely estimated at 22½ per cent. of weight on drivers, but where frosty or wet it should not be estimated as greater than 20 per cent. Well designed locomotives will develop a tractive power equal to this rate of adhesion at 10 miles per hour velocity."

For train weights Mr. Berry gives the equation:

Tons weight of train, including engine and tender =

$$\frac{\text{Tractive Power}}{6 + 20\ (\%\ \text{grade})},$$

and he says:

"In using this formula for estimating the number of trains necessary to handle the tonnage, the weight of freight may be considered as 50 per cent. of the weight of train exclusive of the locomotive."

Mr. Bissell.

This is given as "a fair average for slow and fast freights."

Also, in Mr. Berry's paper, Table No. 6 shows train weights "for Locomotive and Tender Weighing 150.3 Tons in Working Order; Tractive Power, 35 268 Pounds; Weight of Caboose, 17 Tons; Velocity and Frictional Resistance, 6 Pounds per Ton." Unfortunately, he does not give the weight on drivers, but if this be taken as proportional to the weight of locomotive and tender, a comparison with the locomotive described by the writer gives the weight on drivers as 154 800 lb. This is so near to Mr. Riley's figure, 155 156 lb., that the latter has been used below for convenience of comparison. Substituting it in Equation 1, and neglecting fractions, the latter becomes:

$$\text{Tons of train weight behind tender} = \frac{31\,031}{4 + 20\,g} - 150.$$

Adding 17 tons, for the caboose, to Mr. Berry's figures in his Table No. 6, the comparison of train weights given in Table 5 is derived.

TABLE 5.

Compensated Grade.	Tons of Train Weight—Behind Tender.		
	Mr. Riley.	Mr. Berry.	The Writer.
0.5%	2 424	2 054	2 066
0.7%	1 940	1 613	1 574
1.0%	1 492	1 207	1 143
1.1%	1 386	1 109	1 043
1.2%	1 292	1 015	958
1.4%	1 140	887	820

In Table 5 Mr. Berry's figures represent "a fair average for slow and fast freights." Had they been deduced to represent a practicable maximum of train weight, they would have been greater. The writer cannot doubt Mr. Riley's statement that his "rating has stood the test of more than a year's operation under all sorts of conditions," but the question here arises as to what factor shall be used in order to ensure safety against stalling. Where traffic is very congested, the expenses incident upon stalling become a very serious consideration, especially on ruling grades 10 miles or more in length. Also, if an entire engine stage is on a ruling grade, it is questionable economy to load the locomotive up to the limit of its capacity. Hence it is that the economic value of a practicable maximum of train weight must be determined by the governing conditions, and the disparity of values in Table 5 is indicative of the differences which may exist under different conditions.

In calculating the values in Table 4, Mr. Riley has designated a "rolling friction" of 6 lb. per ton of train weight. In order to compare this with a resistance determined by the drawbar pull, it should

be reduced to about 5 lb. per ton. According to the curve of car resistance by Messrs. Crawford and Wickhorst, shown by Mr. Riley in Fig. 3, this 5 lb. points to a car weight of about 20 tons. Since it is not probable that Mr. Riley's loaded cars weigh only 20 tons each, it would have been interesting if he had indicated the form of equation or the method by which he determined the value of 6 lb. per ton—something which would show the effect of variation in the weight per car as indicated by the developments shown on Fig. 3. Mr. Berry's use of a resistance of 6 lb. per ton, qualified as representing "a fair average of slow and fast freights," is consistent, but Mr. Riley's use of this figure cannot be thus considered, without further explanation on his part. Mr. Bissell.

Since Mr. Riley believes that, "from a mathematical and exact point of view, the drawbar pull is a most unsatisfactory figure," he cannot have much confidence in the data, taken with a dynamometer car, which establish the curve of car resistances on Fig. 3, exemplifying the application of the drawbar pull method. The writer prefers the measurement of tractive power in terms of the drawbar pull, rather than in terms of the "cylinder tractive power." One or the other form has its advantages according to the purpose to be served, and, for the case where locomotives are used and the hauls are determined from preliminary tests, the writer believes the method by drawbar pull to be simpler and more direct than by the use of a "cylinder tractive power."

The writer does not know of any case where "slow freight trains" are operated in multiple-unit form. For a service of this kind, the unit would probably consist of a motor car and several trailers, and to this form of train the writer's Equation 2 would apply, each unit being considered as a separate train.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1112

THE ACTION OF FROST ON CEMENT AND CEMENT MORTAR, TOGETHER WITH OTHER EXPERIMENTS ON THESE MATERIALS.*

By Messrs. Ernest R. Matthews† and James Watson.

With Discussion by Messrs. William Mayo Venable, Herbert W. Hatton, John C. Wait, James L. Davis, Robert Brewster Stanton, Eugene W. Stern, Edwin Duryea, Jr., Myron H. Lewis, Theodore Belzner, and Ernest R. Matthews and James Watson.

This paper describes in detail a series of experiments, extending over the past two years, made by the writers, in order to ascertain:

The effects of frost, and alternate frost and thaw, on the tensile strength of cement and cement mortar when mixed with—

(*a*) fresh water, cold or warm,

(*b*) sea-water;

The temperature below which it is detrimental to mix Portland cement concrete;

The effects produced by immersing concrete in—

(*a*) fresh water, hard or soft,

(*b*) sea-water;

Absorption of water by (dry) cement;

* Presented at the meeting of March 3d, 1909.

† Borough Engineer of Bridlington, England.

Quantity of water required to be added to cement to produce complete hardening.

The results of these experiments are not only interesting, but should prove of value to engineers generally.

The Hull Cold Storage Company, of Hull, England, kindly allowed the writers to use its refrigerating rooms in order to obtain the degrees of frost necessary for these experiments. The cement used was that manufactured by Robson's Cement Company, of Hull, and all the experiments were carried out at the laboratories of that firm, in Hull, these being kindly placed at the disposal of the writers.

Cement Used in Experiments.

The particulars of the cement used are as follows: Made on January 28th, 1907. Residues on a 5 776-sieve (that is, having 76 meshes per linear inch) = 0.5%; residues on a 10 000-sieve (having 100 meshes per linear inch) = 2.0%; residues on a 32 400-sieve (having 180 meshes per linear inch) = 11.5% (showing that the cement was ground extremely fine). Specific gravity = 3.112; flour = 54.5%; Le Châtelier tests, expansion = 2.7 mm.; Faija bath test, cement pat sound and hard; time of set of neat cement with 25% water: Initial set = 35 min.; permanent set = 6 hours, in a room kept at a temperature of 60° Fahr.

Tensile Strains. Neat Cement.

7 days	= 685 lb. per sq. in.	British Standard Test,	400 lb. per sq. in.
14 "	= 787 " " "		....
28 "	= 875 " " "	" " "	500 " " "

It will be seen that these results are well above the British Standard Tests.

Tensile Strains. One Part Cement and Three Parts Sand.

Mixed with three parts by measure of sand, and with no hammering of briquettes into moulds, its mean strength was:

7 days	= 200 lb. per sq. in.	British Standard Test,	120 lb. per sq. in.
14 "	= 277 " " "		....
28 "	= 333 " " "	" " "	225 " " "

Chemical Analysis.

	Percentage.
Insoluble residue	0.82
Silica	20.43
Alumina	9.10
Oxide of iron	1.95
Lime	62.65
Magnesia	1.25
Sulphuric anhydride	1.38
Loss on ignition	1.66
Alkalies and loss	0.76
	100.00

The sea-water used in these experiments was taken from the North Sea; the fresh water was drawn from the Hull Corporation mains. To obtain the soft water, the temporary hardness of this water was removed, the permanent hardness being from 3 to 4 degrees.

The experiments herein will be compared with the tests just given, which will be referred to as the "Normal Tests."

Effects of Frost.

The effects of frost, and alternate frost and thaw, on the tensile strength of cement and cement mortar when mixed with (*a*) fresh water—cold or warm, (*b*) sea-water; and the temperature below which it is detrimental to mix Portland cement concrete, were determined by the following experiments:

Experiment A.—In this experiment the writers set out to discover the weakening effect, upon freshly mixed cement, of continuous light frost, temperature 29° Fahr., and of heavy frost, 15° Fahr. Nine briquettes were made with neat cement, 20% water, in the laboratory, the temperature of the air being 60° Fahr. These were taken from the moulds 24 hours after gauging and placed in cold stores, temperature 29° Fahr., and were broken at 7 and 28 days, respectively, the average tensile strength being:

At 7 days = 610 lb. per sq. in.
At 28 days = 905 " " " "

These results are compared with the normal tests as follows:

	Tensile Strength, in Pounds per Square Inch.	
	Normal tests, 24 hours in air at 60° Fahr., in water remainder of time.	In air at 60° Fahr. for 24 hours, then 29° Fahr. for remainder of time.
7 days.....	685	610
28 days.....	875	905

In the 7 days' test it will be observed that there is a decrease of 10.9% in tensile strength, and an increase of 3.4% in the 28 days' test.

Experiment B.—Nine briquettes, made in the same manner as in Experiment *A*, were placed at 60° Fahr. Three were taken out at the end of 2 days, and placed in cold storage for 25 days; three more, at 7 days, for 21 days, and the other three, at 14 days, for 14 days. All were broken at 28 days, the result being as follows:

	Tensile Strength, in Pounds per Square Inch.			
	Normal test in air, 60° Fahr. for 24 hours, then in water.	In water at 60° Fahr. for 2 days, then in air at 29° Fahr.	In water at 60° Fahr. for 7 days, then in air at 29° Fahr.	In water at 60° Fahr. for 14 days, then in air at 29° Fahr.
28 days.....	875	912	977	942

Experiment C.—Nine briquettes, made as before, were allowed to harden in air for 7 and 28 days at 60° Fahr., the result being:

Average tensile strength at 7 days = 443 lb. per sq. in.
" " " " 14 " = 525 " " "
" " " " 28 " = 775 " " "

Days.	7, 14, and 28 days in air at 60° Fahr.	24 hours in air at 60° Fahr., then in water.
7	443	685
14	525	787
28	775	875

Experiment C_1.—

Sand and Cement Tests (3 to 1): Same as Experiments *A*, *B*, and *C*.

Days.	Normal test.	*A*.	*B*.	*C*.
7	200	163	.....	220
14	277	270	.....	250
28	353	342	*B*2. 317 *B*7. 305 *B*14. 243	322

Experiment D.—Effect of Alternate Frost and Thaw.—The briquettes were allowed to remain for 24 hours under damp flannel, then

in water for three days (60° Fahr.), then in water at the cold stores (temperature varying from 29° to 60° Fahr.). The briquettes were changed every three days.

Days.	Neat.	3 to 1.	Normal.	
			Neat.	3 to 1.
14	787	252	787	277
28	813	323	875	353

Experiment E.—This test was the same as *A* or *D*, but the briquettes were gauged with warm water; temperature, 100° Fahr.

Days.	Neat.	3 to 1.	*A* Test.	
			Neat.	3 to 1.
7	352	133	610	163
14	705	205	...	270
28	728	230	905	342

Experiment F.—(*Salt-Water Immersion*).—Nine briquettes were mixed with fresh water, and, after 24 hours, were immersed in sea-water, and broken at 7, 14, and 28 days.

Days.	Neat (20% water).	3 to 1 (10% water).	Normal.	
			Neat.	3 to 1.
7	770	242	685	200
14	742	278	787	277
28	812	360	875	353

Experiment G.—Nine briquettes were mixed with sea-water (same test as before).

Days.	Neat.	3 to 1.	Normal.		Mixed with Fresh Water and Immersed in Sea-Water.	
			Neat.	3 to 1.	Neat.	3 to 1.
7	693	180	685	200	770	242
14	775	287	787	277	742	278
28	773	293	875	353	812	360

Initial set, 9 min.; final set, 6 hours.

Experiment H.—Nine briquettes were mixed with sea-water, and, after 24 hours under damp flannel, were immersed in fresh water for the remainder of the time.

Days.	Neat.	3 to 1.	Normal.	
			Neat.	3 to 1.
7	628	150	685	200
14	733	255	787	277
28	713	297	875	353

Experiment K.—Same test as *A*, but the briquettes were kept in a temperature of 15° Fahr. in cold storage.

K.—Heavy Frost.			*A.*—Light Frost.		Normal.	
Days.	Neat.	3 to 1.	Neat.	3 to 1.	Neat.	3 to 1.
7	405	57	610	163	685	200
28	595	145	905	342	875	353

The briquettes were taken from the cold stores to the laboratory, two miles away, and were broken in a temperature of 60° Fahr., 45 min. after leaving the cold stores.

Experiment L.—The briquettes, 24 hours after gauging, were put into water at 60° Fahr. for 6 days, then placed in the cold stores at a temperature of 15° Fahr. for the remainder of the time.

Days.	Neat	3 to 1.	Briquettes placed in air at 60° Fahr. for a day or two after having been in cold stores at 15° Fahr. for 28 days.		*A.*	
			Neat.	3 to 1.	Neat.	3 to 1.
28	700	217	875	315	905	342

Experiment M.—The briquettes were put directly into the cold stores at 29° Fahr. for 7 days.

Days.	Neat.	Normal—Neat.
7	480	685
28	595	875

Experiment N.—The briquettes were made with neat cement, and placed, some in air at a temperature of 60° Fahr., and others in air at a temperature of 29.3° Fahr. (2.7° of frost). In 15 min. those in air at 60° Fahr. were still soft, while those subjected to frost had just frozen hard at the expiration of that time. Briquettes mixed with sand and cement (3 to 1) were subjected to a similar test. At the expiration of 15 min. those in a temperature of 60° Fahr. were still soft, while those in a temperature of 29.3° Fahr. had just frozen hard; and at a temperature of 27° Fahr. (5° below freezing point, Fahr.) were frozen very hard indeed at the expiration of that time.

Conclusions from the Foregoing Experiments.—These investigations have led the writers to the following conclusions:

(1) That light frost occurring 24 hours after the cement has been gauged, as indicated in Experiment *A* (3° of frost, or thereabouts), is detrimental to freshly mixed Portland cement, but only for a short time, and that at the end of 28 days it has quite regained its normal strength. If the frost occurs immediately after the cement has been gauged, the effect is more detrimental, and would appear to be permanent (see Experiment *M*). A minimum quantity of water should be added in frosty weather.

(2) That heavy frost (17° of frost, or thereabouts) has a most injurious effect (permanent) upon freshly mixed cement (neat), and cement mortar, as shown in Experiment *K*.

(3) That a light frost (3° of frost, or thereabouts), as indicated in Experiment *A*, does not affect cement or cement mortar if it has attained 2 days' set previous to the occurrence of the frost (Experiments *B*, *C*, and *D*).

(4) That the detrimental effect of light frost upon cement mortar (3 to 1) occurs more immediately than upon neat cement, but that cement mortar recovers from the ill effects of frost more rapidly than neat cement. At the end of 14 days it has quite recovered (Experiment *C*).

(5) That the mixing of cement or cement mortar with warm water (temperature, say, 100° Fahr.), which is sometimes done in frosty weather, and has been recommended by some engineers,* has a permanently injurious effect upon cement and cement mortar. This will be seen by reference to Experiment *E*.

* *Minutes of Proceedings*, Inst. C. E., London, Vol. CXXXIV, p. 384.

(6) That neat cement immersed in fresh water immediately after becoming set, and remaining in water, has a much greater tensile strength than when remaining continuously in air (Experiment *C*), the former being 55% stronger than the latter at the end of 7 days, 50% stronger at 14 days, and 11.3% stronger at 28 days. In 3 to 1 cement mortar, however, the result is different, the tensile strength being practically the same under both conditions.

(7) That it increases temporarily the tensile strength of cement and cement mortar to immerse them in sea-water 24 hours after gauging, instead of immersing them in fresh water; but the increased strength is only temporary (Experiment *F*).

(8) That there is an immediate reduction in the tensile strength of briquettes mixed with sea-water and immersed in sea-water (Experiment *G*) over those mixed with fresh water and immersed in sea-water (Experiment *F*). At the end of 14 days the strength of the former equals that of the latter, but after that period a depreciation again sets in, so that at 28 days there is a deficiency of 5% in the tensile strength.

(9) That the initial set of briquettes mixed with sea-water is 9 min.; permanent set, 6 hours. When mixed with fresh water, the former is 35 min.; the latter, 6 hours (Experiment *G*).

(10) That cement and cement mortar mixed with sea-water, and immersed in fresh water 24 hours afterward, have less tensile strength than when mixed with fresh water and immersed in fresh water (Experiment *H*).

(11) Experiment *L* shows that 17° of frost for 28 days does not kill the process of hardening in the briquette, but only delays it.

(12) It would appear from Experiment *N* that it is detrimental to concrete to mix it when the temperature is below 29.3° Fahr. (2.7° of frost), that being the freezing point of cement and concrete.

The Effects Produced by Immersing Concrete in Fresh Water (Hard or Soft), and in Sea-Water.

Neat Cement.—Neat-cement briquettes (mixed with 20% of fresh water) were immersed in fresh water (both hard and soft) and in sea-water after being in the moulds for 24 hours. In each case the absorption finished at the end of the seventh day: (1) The water absorbed by the briquettes in hard water at the end of the seventh

day = 3.46%; (2) by the briquettes in soft water = 2.92%; (3) by the briquettes in sea-water = 3.92 per cent.

Sand and Cement, 3 to 1.—As in the case of neat cement, just described, no absorption took place after the seventh day. (1) The briquettes in hard water absorbed at the end of the seventh day 3.4% of water; (2) in soft water, 3.4%; (3) in sea-water, 4.5 per cent. In the case of neat cement, and sand and cement briquettes, similar to the foregoing, but exposed to air for 7 days previous to immersion in water, the following results were obtained:

With neat cement during 7 days' exposure to air, the loss in weight was 1.7%; then, after 24 hours' immersion in (1) hard, (2) soft, and (3) sea-water, the increased absorption = 1.7%, just counterbalancing the previous loss. On continued immersion a further gain of only 0.3% in weight was obtained. The results of tensile tests at 28 days were: (1) = 875 lb.; (2) = 760 lb.; and (3) = 835 lb. per sq. in. The lower absorptions were most probably due to the partial set of the cement in the center of the briquettes during the 7 days' drying in the air, and the prevention of the free percolation of the water through it.

With sand and cement, during 7 days in air, the loss of moisture was 2.2%; then, after 24 hours' immersion, the gain was: (1) in hard water = 3.4%; (2) in soft water = 2.0%; and (3) in sea-water = 2.8 per cent. The results of tensile tests at 28 days were: (1) = 360 lb., (2) = 360 lb., and (3) = 330 lb. per sq. in.

Conclusions from the Foregoing Experiments.—(1) That no absorption takes place in neat cement, cement mortar, or concrete after immersion in water for 7 days.

(2) That neat cement immersed in hard fresh water for 7 days absorbs 0.54% more than when immersed in soft fresh water for the same period.

(3) That if immersed in sea-water for 7 days it absorbs 0.46% more than when immersed in hard fresh water, and 1.0% more than when immersed in soft fresh water.

(4) That cement mortar (3 to 1) absorbs the same quantity when immersed in either hard or soft fresh water, but when immersed in sea-water it absorbs 1.1% more.

(5) That neat cement and cement mortar, when immersed in hard fresh water, have practically the same absorption in both cases.

That neat cement immersed in soft fresh water absorbs 0.48% less than cement mortar (3 to 1), and that neat cement immersed in sea-water absorbs 0.58% less than cement mortar.

(6) That when neat cement is exposed to air for 7 days after gauging it loses 1.7% of its weight, but when immersed for 24 hours in water, either hard or soft fresh water, or sea-water, it absorbs 1.7%, which just counterbalances the previous loss.

(7) That after this loss has been made good, and the immersion of the briquettes is continued, there is a further gain of 0.3%, which averages 1.43% less than the absorption which takes place when cement is immersed in water 24 hours after gauging.

(8) That cement mortar (3 to 1) exposed to air for 7 days after gauging loses 2.2% of its weight; but after 24 hours' immersion in hard fresh water the absorption is increased to 3.4%; in soft water it is 2.0%, and in sea-water it is 2.8%, showing that soft water is absorbed more slowly than hard water, and that sea-water is also more slowly absorbed than hard fresh water.

Absorption of Water by (Dry) Cement.

Experiment 1.—Dry cement was compressed into moulds with a press, the same amount in each mould. The moulds were then allowed to stand in water for 24 hours. The result was an average increase in weight of 14.9 per cent.

Experiment 2.—The cement in the moulds was then changed so that there would be a variation in thickness of $\frac{1}{8}$ in. The result was that the absorption varied correspondingly from 13.2 to 17.1 per cent. The writers then took a larger quantity of cement and compressed it into the same bulk as at first, and found that the absorption after 12 hours = 12.3%; after 24 hours = 14.4%; after 48 hours = 14.8%; after 4 days = 15.1%; after 8 days = 15.4%; after 31 days = 16.8% (constant).

Conclusions from the Foregoing Experiments.—(*a*) That when neat cement is immersed in water for 24 hours it absorbs from 14.4 to 14.9%, according to the thickness of the cement;

(*b*) That the absorption increases to 16.8% at the end of 31 days' immersion;

(*c*) That no absorption takes place after 31 days' immersion.

Quantity of Water Required To Be Added to Cement to Produce Complete Hardening.

According to the formula laid down by Le Châtelier,*

$$3CaO\ SiO_2 + \text{water} = CaO\ SiO_2\ 2\tfrac{1}{2}\ H_2O + 2Ca\ (OH)_2$$

35.4% of water would be required to be added to cement for complete hardening, and the hardened cement, therefore, would contain 26.2% of water in a combined state. From the figures the writers now give, this is found to be by no means the case. Possibly the reaction is not so complete, as Le Châtelier works it out by theory, and, although more water is combined by using an excess in gauging, yet the test becomes less and the strength is impaired, for Dr. Michaelis† found that, by sealing up some very finely ground cement with 150% of water for four weeks and then drying it over sulphuric acid, a loss on ignition was shown which equalled 27.5% of water absorbed. The results of the writers' experiments are as follows:

Experiment A.—Neat-cement test pieces gauged with 20% water, after 14 days' immersion in water, gave free moisture = 11.75%, combined = 9.7%; after 28 days' immersion they gave free moisture = 12.14%; combined = 10.9 per cent.

Experiment B.—Mortar briquettes, with 3 sand to 1 cement, gauged with 10% of water, after 24 hours were immersed in water and kept there for 7, 14, and 28 days:

	Free water at 105° cent. Percentage.	Combined water. Percentage.
At 7 days	9.44	9.20
" 14 "	8.49	10.58
" 28 "	8.68	10.29

Experiment C.—Neat cement test pieces were gauged with 20% of water, and, after 24 hours under damp flannel, were immersed in fresh water for periods up to 18 months.

	Free water at 105° cent. Percentage.	Combined water. Percentage.
After 3 days	8.0	6.4
" 7 "	8.9	7.9
" 28 "	9.0	12.38
" 3 months	9.25	13.05
" 6 "	9.55	12.95
" 12 "	9.40	12.90
" 18 "	9.82	12.20

* *Annales des Mines*, 1887.

† *Thonindustrie-Zeitung*, 1899.

Experiment D.—Other test pieces, made of different cement, were also tried, 20% of water being used for gauging, with the following results.

	Free water. Percentage.	Combined water. Percentage.
After 24 hours.....	8.5	3.3
" 48 "	7.45	11.5
" 72 "	7.10	7.7

Experiment E.—Frozen Test Pieces.—The cement was gauged with 20% of water, and, after 24 hours under damp flannel, was placed in cold storage at 15° Fahr. (17° of frost) for 6 days. The free water = 10.29%; combined water = 5.92 per cent. There was no active hardening of the cement.

Conclusions from the Foregoing Experiments.—That from the quantity of water absorbed by cement and cement concrete the writers are unable to determine precisely its ultimate effect upon the hardening of the concrete. It depends entirely upon physical conditions, such as the porosity of the concrete. When an excess of water is added, there seems to be a loss due to evaporation during the few hours after gauging; then, although immersed in water, the percentage of uncombined water remains constant, while the percentage of combined water increases until it attains a maximum of approximately 12 per cent. This occurs also with gauged cement exposed to open air, the only difference being that the quantity of free moisture gradually diminishes, owing to evaporation. In the case of sand and cement mortar, more water is absorbed in proportion to the quantity of cement used; this, most probably, is due to the greater porosity of the mass. The same result, it will be noted, occurs in the case of cement compressed into moulds, less water being absorbed in the same period when the mass is denser in bulk; so that, in the case of fire-proof floors and reinforced work, the denser the concrete, and with no more than the maximum quantity of water used to obtain a perfect gauging, the more fire-proof will be the mass, and less subject to dilatation through the expansion of unnecessary water. In the case of the test pieces subjected to hard frost, the process of hardening has been stayed, and, although the proportion of water used was the same as in Experiment *C*, yet in the same period of time 20% less

of the water had gone into combination, preventing the cement from attaining its normal strength.

The writers have endeavored to present what, in their opinion, is useful information concerning the behavior of Portland cement, cement mortar, and concrete, under various conditions. This information has been obtained by carrying out the series of experiments described herein, in which 727 briquettes were broken.

DISCUSSION

Mr. Venable.

WILLIAM MAYO VENABLE, M. AM. SOC. C. E. (by letter).—The writer is much interested in this valuable paper, having had experience with the effect of frost on concrete, and the effect of using salt water in mixing concrete.

In the construction of the Long Key Viaduct, on the Florida East Coast Railway, the concrete was at first mixed with fresh water only; but, owing to the expense of supplying fresh water for this purpose, so many miles from any natural source of supply, salt water was finally used, it being believed that it would not have an appreciably injurious effect. On pier work it was customary to allow the cofferdams to fill with salt water before the removal of the forms, and in less than a day after the placing of the concrete; and it is interesting to note that the tests set forth in *Experiment F* and *Experiment G* indicate that no appreciable difference in the strength of concrete mixed with fresh water and that mixed with sea water need be expected. The writer's reason, however, for preferring fresh water was doubt as to the action of the salt water on steel reinforcing rods.

The conclusion that mixing cement mortar with warm water has a permanently injurious effect, if not requiring some modification, is most important, as this is far the easiest way by which the temperature of materials for concreting in freezing weather may be raised sufficiently to cause the concrete to set. On all the sections of the sewer system now under construction in Louisville, Ky., concreting is permitted when the temperature is above 24° Fahr., but the sand, gravel, and water must be separately heated before mixing. The concrete is hardly likely to be frozen after being deposited, owing to its protected location. If any person has investigated the subject of the effect of temperature, above freezing, upon the strength of concrete, and the rapidity with which the full strength is acquired, the data obtained ought to be communicated. It may be that the heating of the ingredients separately is as injurious as the separate heating of the water; or that heating the water is injurious only when it raises the temperature of the resultant mixture above a certain point. The practice of heating concrete materials, generally the water, to remove frost in gravel and sand, and thereby obtain concrete at about 60° in the forms, thus securing sufficiently rapid initial set, is quite general, and some method of heating is necessary if concreting is to be done at all when the outside temperature is below freezing.

Can any person furnish the results of a series of tests upon mortar mixed with warm water, showing to what temperature the water, or the mortar, may be raised without injury to the ultimate strength to be acquired? The writer, in mixing concrete, has frequently heated water to more than 80° Fahr., producing concrete at 54° or higher as

Mr. Venable. it left the mixer, and has never discovered any weakness in such concrete; and if the heating of the water alone is not injurious, below a certain temperature, it is much better than heating the sand and gravel separately, because it is simpler and more economical than any other method.

Mr. Hatton. HERBERT W. HATTON, JUN. AM. SOC. C. E. (by letter).—In reviewing this very excellent paper, the constructing or field engineer at once seeks to make comparisons between the respective tests recorded and actual construction under similar conditions; for, after all, it is the results obtained in the field under alternate conditions of frost and thaw which are of paramount importance.

The conditions under which concrete is tested in a laboratory are vastly different from those encountered in the field; for example, suppose 100 cu. yd. of concrete to be mixed between temperatures varying from 28 to 40° Fahr.—and this is frequently the case—the main differences between concrete mixed in the laboratory and concrete mixed on the work will be:

First.—The cement used in one case has been practically kept in cold storage, and its actions in setting are retarded, whereas that used in the testing laboratory is kept practically at 60° Fahr., summer heat, hence crystallization begins at once upon the making of the test pieces.

Second.—The water used in mixing the concrete is usually very cold, or it is heated until it is quite hot, and, in either case, setting is greatly retarded.

Third.—The ingredients forming the concrete are either cold or they may be heated; in the one case they may be full of frost, and, in the other they may be so hot as to absorb readily large quantities of water from the cement and needed by it in crystallization.

Fourth.—Concrete mixed when the temperature is 29° Fahr., or thereabout, will get neither its initial set nor hard set as quickly as that mixed when the temperature is 60° Fahr., nor is it possible in all cases to maintain the surrounding atmosphere at a temperature of 60° Fahr. for 24 hours, except at considerable expense.

It seems to the writer that the result of the action of frost and thaw on concrete can best be obtained from actual cases in the field. It is true that practical tests, at a great deal more expense, can readily be made under actual working conditions, and possibly such tests could be made by the committee which has received the Government appropriation, set aside for the past year or more, for testing concrete beams, etc. This paper, however, is quite a valuable asset to the literature on this subject.

An actual case of recent date, where concrete was placed when the temperature varied many degrees, may be of interest. During the early

part of the winter of 1908, the writer was engaged upon the construc- Mr. Hatton.
tion of a large dam at Berwick, Pa., and incidental thereto, the spillway of an old dam had to be torn out and replaced. Cold weather came at a time when the entire paving, concrete apron, etc., of the spillway, had been removed, and it was necessary to repave and concrete before the spring freshets came; this necessitated the placing of the concrete covering and apron at the toe regardless of the weather conditions.

The spillway was 60 ft. wide and about 55 ft. long, with a slope of 1½ to 1. The thickness of the concrete was 7 in. The number of square feet of concrete placed each day was too great to heat readily. During the mixing of the concrete, the temperature ranged from 28 to 40° Fahr., much of it being mixed at the lower temperature. The stone was full of frost, as was the sand, and the water came directly from the dam, ice being broken in order to get it. The cement was stored in a shed, the temperature within which was the same as the outside atmosphere.

In all cases the sand was heated by a fire, kept constantly burning within a 16-in. cast-iron pipe, the sand being spread over and around the pipe. The water was also heated until it steamed. In using the water, the practice was to empty two buckets of ice water into the large kettle each time two buckets of water were taken therefrom for mixing concrete, and in this way the temperature of the water used in mixing was reduced so that it had no harmful effect on the concrete. Several barrels of cold water were kept close at hand for this purpose.

The heated sand and the cold cement were first mixed thoroughly, and the stones were placed thereon, then the warm water was poured over the stones, and in this way the temperature of the water was further reduced, so that on the completion of the mixing the temperature of the mixture rarely exceeded 50° Fahr.

In no case was the mixing carried on when the temperature was below 27° Fahr., and whenever the thermometer stood below freezing the concrete was covered as fast as it was placed.

In order to ascertain how much covering of manure was necessary to insure the non-freezing of the concrete under varying conditions of temperature, the following experiment was made.

Small quantities of concrete were mixed as described, and, when placed, were immediately covered with cement bags, or with tarpaulins, upon which hot manure was spread. The temperature on two occasions dropped to 10° Fahr., but, with a covering of manure 8 in. thick, the concrete was in no case affected. Coverings 4 and 5 in. thick were found insufficient, as this small body did not contain heat enough in itself to continue to generate heat from the phosphorus, ammonia, etc., therein contained, and in two days' time the frost practically went through it.

Mr. Hatton. Almost every night the temperature dropped to 24° Fahr., frequently went down to 15 or 16°, and on two occasions down to 10° Fahr., but the covering, which was 8 in. thick, on top of cement bags or tarpaulins, proved adequate, except when a rain occurred, and the covering got wet, and then even a thickness of 8 in. was insufficient, as the water dripped down through the manure, and when the temperature dropped, as it usually did after each rain, the frost went through the covering, forming a heavy white frost directly on top of the tarpaulin and also reaching the concrete. Therefore, whenever a rain occurred, in case the concrete had not already obtained its hard set, it was necessary to take off the old manure and replace it with a fresh covering.

The manure was obtained from the contractor's mules, which were kept within a few hundred yards of the operation, thus the only cost connected with the covering of the concrete was the hauling and the spreading. The farmers in the vicinity were eager to collect the manure and haul it away without cost, after it had been used for this purpose.

Nazareth cement was used on the work, and was very slow setting. In some cases, when mixed in concrete, it did not obtain its hard set in from 30 to 40 hours.

The following method was used to determine whether, in any instance, the frost had worked beneath the covering: Before placing the tarpaulin several quarts of water were poured over the concrete where there was a slight hollow place or indentation, and this water was added to, until the concrete had taken up all it would hold. It was not necessary to add more water after the concrete had obtained its hard set, and in no case was there the slightest indication of freezing during a daily examination for five consecutive days.

In a couple of instances the writer had the manure covering removed within four days, but there was still considerable moisture in the concrete, and on the surface, due to the manure. This moisture was soon frozen, and after a subsequent thaw, the top surface could be scraped or peeled off.

The practice thereafter was to leave the covering on for at least a week or ten days. When it was removed, the concrete was in first-class condition, and apparently continued to harden uniformly. In using pick and sledge on this concrete, the writer found that, as far as he could judge, it had set just as well as if it had been mixed under the most favorable conditions.

This is directly in line with the statements of Messrs. Matthews and Watson, to the effect that if a cement or concrete obtains its hard or final set before being exposed to frost, it will, upon exposure, continue to crystallize and harden.

The hot water with the frosty stone had a tendency to create a normal condition under which the cement suffered no injury.

Considerable care should be taken, however, to protect the manure

from becoming wet during rain storms. If possible, it should be covered with tarpaulins, or with planks arranged in such a manner as to exclude the water. This is a practical and yet a very inexpensive way to protect concrete in the open where a low flat surface is presented. Mr. Hatton.

From this experience, the writer has no hesitation in saying that, in his opinion, if concrete is properly mixed and protected until it has obtained its final or hard set, a frosty atmosphere, with the temperature in the neighborhood of 28 or 29° Fahr., has no permanent or detrimental effect upon it.

JOHN C. WAIT, M. AM. SOC. C. E.—Some twenty-four years ago the question of the use of cement in freezing weather was discussed before this Society, and the speaker supposed it had been settled. Mr. Wait.

In South Chicago, twenty-four years ago, the temperature being from 10 to 24° above zero, the speaker put in foundations for large and heavy car shops, and then built the walls, all being laid with Portland cement mortar. In the following summer, having occasion to dig them up to put in sewer pipes, they were found to be perfectly set and strong. The speaker agrees with Mr. Stern, who has said that, if concrete foundations can be buried or enclosed so as to let the frost come out at its leisure, the concrete will set in time.

The great power station and pulp mills at Rumford Falls were put in during extremely cold weather, but the speaker has never heard that there was any trouble with them. The foundations carry very heavy machinery, and are considered a good piece of work.

It would seem that the subject of heating is one that is much feared, and without reason. In the month of November the speaker visited Youngstown, Ohio, where he saw concrete mixed with Atlas cement and with slag cement and poured into moulds that were steam-jacketed and heated, so that the mixture boiled and steamed. In from 5 to 7 min. the concrete was taken out of the moulds and handled in the form of blocks, the walls and partitions being from $\frac{1}{2}$ to $\frac{5}{8}$ in. thick. These concrete blocks were put on cars and run into steam-rooms, where they were allowed to set. The speaker never saw any better ultimate result with concrete than these blocks, and they are now used extensively in Youngstown for the construction of houses.

Heating the water, or heating the sand or the stone does not hurt concrete materially unless it is superheated, and certainly if it is not heated above the boiling point.

It would be enlightening to hear an expression of opinion from those who may have seen this work at Youngstown, or who have had experience with heated concrete.

JAMES L. DAVIS, ASSOC. M. AM. SOC. C. E.—The authors have given the results of a comprehensive series of tests on Portland cements which will be read with much interest by all users of this material. Mr. Davis.

Mr. Davis. The speaker does not know of a similar series of freezing tests having been made where the temperature conditions were so well controlled, or of tests in chemically-treated water which are equal to these in scope. It is to be regretted that the tests could not have been carried beyond the 28-day period. The speaker's experience in testing cements leads him to believe that in experimental work, like that undertaken by Messrs. Matthews and Watson, it is very desirable that the tests be carried beyond the 28-day period, and to at least 3 months. Cements which differ in strength quite widely at early ages approach each other in strength at 3 months' age, cements having a high early strength gaining slowly with age, and those of low early strength gaining rapidly. This is brought out clearly in Bulletin No. 321 of the United States Geological Survey, where 6 months is the period noted as being necessary for the best results. The higher strength resulting from the greater age renders the unavoidable imperfections of making, storing, and testing the specimens of relatively less effect than at earlier ages. It is the speaker's belief that the ultimate strength of cement and concrete can be foretold fairly well from 3-month tests, but not from much earlier ages. Three-month tests are not as necessary in routine work under familiar conditions. The contention is not made that the conclusions to be drawn from the investigation would have been altered in the main by 3-month tests, but some of them might have been modified, and all would have been better assured.

This paper presents valuable information on the all-important material, Portland cement.

Tests on Natural and Improved Cements.

The results of a series of tests on natural and "improved" cements, involving unusual conditions of exposure, in some respects resembling those used by the authors, may be of some interest.

The results are taken from the records of the laboratory of the Board of Water Supply of the City of New York. Four brands of cement were used, two natural cements, and two of the "improved" class made by grinding together definite proportions of natural and Portland cement clinker. The tests were made in neat cement and in mortar, in proportions of 1:2 and 1:3. The purpose of the tests was to determine to what extent injury, during the hardening period, would result from exposure to extremes of temperature and moisture somewhat greater than would ordinarily occur under construction conditions.

Exposures Made.—Sets of six briquettes were made up for tensile tests at 28 days' and 3 months' age for each of the following conditions of storage or exposure: Storage in laboratory air; storage in damp sand; storage in open air, during which frequent freezing occurred; heating at a temperature of 212° Fahr. for 4 hours in dry air; boiling

in water for 4 hours. Sets of six specimens were given regular or normal storage in water at about 65° Fahr., in order to serve as a basis for comparison. Mr. Davis.

Preliminary Storage.—The exposure tests were intended to follow good construction practice where green concrete is protected from the extremes of temperature for a period of from 24 hours to several days. Exposure after two conditions of preliminary storage was carried out in all cases, (*m*) 24 hours after moulding, the storage for this period being in the damp closet; (*n*) at 7 days' age, with 24 hours in the damp closet and 6 days in water. The series, therefore, was a double one. The number of briquettes tested was 1 372.

Conditions of Exposures.—In storage in laboratory air the temperature was about 65° Fahr. during the day, but dropped several degrees at night. In sand storage, the specimens were kept buried in damp sand in the laboratory basement, where the air temperature was about 60° Fahr. The freezing tests were made by exposure on the laboratory roof during January, February, and March, 1908. The number of days the temperature was below freezing during the 28-day tests was from 16 to 23, varying as necessitated by the preliminary storage the specimens received.

The 3-month specimens were subjected to freezing between 41 and 58 days. One brand of "improved" cement, being the last of the series to be made up, was not exposed to freezing more than 18 days under treatment (*n*). The minimum temperature to which the specimens were exposed was about 5° Fahr.

The dry and wet heating exposures were made at the termination of the periods of preliminary storage, the specimens being then put in regular storage in water to await breaking.

The severity of the exposures was judged in part by noting the individual variations in strength from the mean strength of each set of six specimens, the variations being expressed as percentages of the mean strength. In other words, lack of uniformity in strength in a set of specimens was considered a measure of the severity of the exposure conditions. The detailed values are not given herewith, but were considered in summarizing the results.

Basis for Comparison of Results.—In Table 1 the results have been grouped as neat, 1:2, and 1:3. With very few exceptions, there is progressive increase in strength with age with each cement in each group, and with each kind of exposure. The effects of the various exposures, therefore, may be studied by comparisons of the averages of all the groups for each exposure. In other words, whatever the cement, the proportions, or the exposure, the effect on strength is qualitatively the same. There is an exception to this with storage in laboratory air, but it is not important.

Mr. Davis.

TABLE 1.—TENSILE TEST OF CEMENT. EFFECT OF EXPOSURE ON STRENGTH.

Cement.	Sand.	Regular Storage.		Strength, 28 Days					Strength, 3 Months.				
		28 Days.	3 Months.	Freezing.	Laboratory Air.	Sand Storage.	Boiling.	Dry Heating.	Freezing.	Laboratory Air.	Sand Storage.	Boiling.	Dry Heating.
NEAT.				After 24 hours in damp closet. Treatment (*m*).									
Natural No. 1	.....	203	302	281	475	231	255	151	406	381	325	383	313
" No. 2	.....	200	276	445	325	273	163	118	391	407	305	241	196
Improved No. 1	.....	323	398	254	429	329	211	251	555	494	405	315	322
" No. 2	.....	498	496	306	595	430	307	381	535	514	488	396	500
1 : 2													
Natural No. 1	Ottawa.	225	361	254	231	180	159	179	254	167	318	418	262
" No. 2	"	168	277	265	233	241	....	91	383	212	340	....	175
Improved No. 1	"	259	382	196	241	241	148	238	509	261	404	360	402
" No. 2	Quartz.	178	326	212	177	243	141	205	443	209	330	264	304
1 : 3													
Natural No. 1	Ottawa.	100	171	217	121	129	83	85	291	130	256	234	177
" No. 2	"	92	193	189	137	162	114	70	317	122	264	172	117
Improved No. 1	"	....	....	178	125	160	112	150	361	156	279	206	284
" No. 2	Quartz	190	160	175	93	151	106	123	296	92	257	181	190
Averages	.....	219	304	248	265	229	150	170	395	262	330	263	273
NEAT.		After 7 days regular storage. Treatment (*n*).											
Natural No. 1	.....	....	....	271	487	187	203	89	404	360	256	317	222
" No. 2.	.....	....	....	365	324	210	146	118	387	505	253	201	197
Improved No. 1	.....	..	....	406	566	315	228	296	629	669	354	298	374
" No. 2	.....	....	....	477	629	406	353	266	355	474	485	401	395
1 : 2													
Natural No. 1	Ottawa.	....	....	292	223	173	86	55	279	206	324	265	210
" No. 2	"	....	....	225	197	175	124	138	355	296	304	138	236
Improved No. 1	"	....	....	250	333	243	141	235	505	397	414	263	375
" No. 2	Quartz.	....	....	319	261	231	173	177	608	272	309	241	300
1 : 3													
Natural No. 1	Ottawa.	....	....	194	114	108	62	69	314	118	233	185	162
" No. 2	"	....	....	170	158	107	119	88	332	198	248	182	200
Improved No. 1	"	....	....	192	146	152	107	182	383	207	260	195	257
" No. 2	Quartz.	....	....	187	154	135	89	120	441	146	204	160	216
AVERAGES	.....	....	....	279	299	205	152	153	416	320	307	237	262
MEAN AVERAGE	.....	....	....	264	282	217	151	161	405	291	318	250	267
RELATIVE PERCENTAGES	.....	....	....	120	128	99	69	73	133	96	104	82	88

Comparison of the average variations in strength shows that regular storage gives the most uniform results, though not the highest strength. Regular storage, therefore, is taken as the standard for comparison. Mr. Davis.

Comparative Effect of Various Exposures, and Conclusions.—In Table 1 the means of the columns are not practical strength values, as they are averages of mixes in three proportions, but their comparison gives the relative effects of the different exposures.

(*a*) The difference between the two methods of preliminary storage referred to as (*m*) and (*n*) is practically negligible; the averages do not vary from the mean average more than 10% for any exposure.

(*b*) In general, there is a consistent increase in strength with increasing richness of proportions with all exposures. The effects are, therefore, not to destroy the normal properties of the cements, but to modify them.

(*c*) Based on mean averages and referred to regular storage, the relative effects on strength are as follows: Freezing exposure: strength at 28 days, 120%; at 3 months, 133 per cent. The average percentage of variation of the individual briquettes is greatest for this exposure, and notwithstanding the high average of strength, this would be considered one of the most severe tests in its result because of the great variations in strength. In treatment (*m*) the number of times freezing occurred exceeds somewhat the number of times in treatment (*n*). The strength in treatment (*m*) was slightly lower. This may not be due to the greater number of times frozen, for similar results are noticed with laboratory air exposure. The increase in percentage of strength at 3 months is accompanied by an offsetting increase in variations of individual values. These tests show that a moderate amount of freezing is not destructive.

The freezing-test results agree in general with the conclusions of Messrs. Matthews and Watson concerning the effects of light frost.

(*d*) Storage in laboratory air: strength at 28 days, 128%; at 3 months, 96 per cent. Next to freezing, this exposure gives the greatest variation of individual values. There is a slight gain in strength between the 28-day and 3-month periods, but a decrease in percentage of gain relative to regular storage. Accompanying the loss in relative strength there is an increased variation in individual values. These tests indicate the necessity of preventing concrete from drying freely in warm air, for the best results, and confirm the general experience that storage in air gives high early strength and subsequent relative loss.

This last, as applied to Portland cements, is more generally true for neat mixes, but, with decreasing richness in proportions, the results are usually reversed. Yet, in this series, the neat briquettes were increased in strength by air storage, while the mortars usually decreased. The increase in strength given is misleading unless it is

Mr. Davis. noted that it is confined chiefly to the neat tests. These results conflict with Conclusion (6), page 327, of Messrs. Matthews and Watson, in giving the higher neat strength and lower mortar strength when stored in air.

(*e*) Storage in damp sand: strength at 28 days, 99%; at 3 months, 104 per cent. This exposure ranks next to regular storage in giving minimum variations of strength. The results are closely comparable with regular storage results, and the tests indicate that green masonry buried in ordinary earth gains strength at a normal rate.

(*f*) Boiling test: strength at 28 days, 69%; at 3 months, 82 per cent. Dry heating test: strength at 28 days, 73%; at 3 months, 88 per cent. These two treatments give very similar results; the boiling seems to be slightly the more severe. The variations in strength are noticeably less than in freezing or in dry air. The effects at the 28-day period are quite marked, but there seems to be a tendency toward recovery, as shown by the actual and relative gains in strength and decrease in variations at the 3-month period.

One of the natural cements, in proportions 1:2, disintegrated in the boiling test. This is the only case of a complete failure of any set of samples in any test. With the exception of this boiling test, only very infrequently did even a single briquette in the sets of six, in which all tests were made, fail completely in strength. The general effects of moist and dry heat are the same.

The tests indicate that natural cement masonry, designed with ordinary factors of safety, could be exposed to moderate heat, either moist or dry, before having attained any considerable degree of strength, without danger. The result would be a lowering of strength, but not to the danger point. As but a single test among the four brands failed completely in either boiling or dry heating, it is probable that, by reasonable specifications and inspection, cements could be readily secured from these classes, and especially from the "improved" class, which would render construction possible, if necessary to build where structures would be exposed to extreme conditions of heat during the hardening period.

(*g*) In general, these severe tests have shown much less influence than is ordinarily supposed to result from such conditions of exposure. If the temperature of natural cement concrete be maintained normal for 24 hours after placing, the critical period will have passed, and hardening and progressive increase in strength will develop thereafter under a wide range in temperature conditions.

Mr. Stanton. ROBERT BREWSTER STANTON, M. AM. SOC. C. E.—Some twenty-two years ago the speaker had the honor of discussing this same subject, and relating some of his experiences in the field. It might not be out of place to state the facts again, for possibly some of the younger members of the Society have not read the *Transactions* that far back.

Mr. Davis has given some very good rules for protecting newly laid masonry and fresh concrete in freezing weather, all, however, being based on "keeping the mortar in a normal condition for the first twenty-four hours." It is not always possible to keep mortar or anything else in a normal condition, even for twenty-four hours, especially when laying railroad track rapidly in a wilderness. Mr. Stanton.

In 1878, when the speaker was engaged in railroad work in Eastern Tennessee, the track-layers, on reaching one of the great iron viaducts in the mountains, found that during the preceding fall one of the piers had been pushed out of position by a landslide. It was necessary to rebuild that pier at once, and, in those days, it was most difficult to find anything in the Cumberland Mountains in a normal condition. It was a very cold winter, the thermometer, at that particular time, ranging from 6 to 10° below zero.

The pier was torn down; ordinary cement mortar was mixed—using Louisville cement—with a good quantity of fine, dry, table salt (the exact proportion of salt used cannot be stated), and the pier was rebuilt with this mixture. No means were taken to protect the mortar other than the use of salt. In a few days the viaduct was erected, and trains were run over it, without the least effect on the masonry, which seemed to have "set" perfectly. The next summer, when the hot weather came, the pier began to sweat, and the salt ran out and coated it with a white deposit, but no effect or change could be noticed in the mortar. As far as known, trains have been running over that viaduct for thirty years, and the pier is as sound as if it had been built in warm weather.

About three years later, while the speaker was building a roundhouse in the yards of the Union Pacific Railway in Denver, Colo., it became necessary to lay some masonry during very cold weather. It was one of those winters peculiar to Denver, the nights being very cold—with the thermometer at or below zero—and the bright sunshine of the day raising the temperature well above freezing.

The stone masonry was laid with ordinary lime mortar, with which was mixed a quantity of fine, dry, table salt. The mortar was used mostly during the warm sunshine of the day, but at night it was entirely exposed to a zero temperature. Great care was taken to fill every joint full of mortar. That the work was well done, and that the mortar "set" perfectly, was shown by the fact that during the next summer, an engine got away in the roundhouse, and ran through the back wall, and, in doing so, took out the pier between two large arched windows. The keystone and one-half of the arch of one window, and two-thirds of the arch of the other, with the wall above them, hung by the mortar in perfectly solid form.

These experiences are given to show that perfect results can be

Mr. Stanton. obtained in cases where it is impossible to use any of the mechanical means suggested to keep the mortar in a normal condition—preventing it from freezing—even for twenty-four hours.

Under such circumstances, of course, special care should be taken in the execution of the work. One of the greatest defects in all classes of masonry is the fact that all the joints, both vertical and horizontal, are not thoroughly and completely filled with mortar, thus preventing a perfect bond, and weakening the whole structure. The same fact applies to concrete foundations and reinforced concrete walls; particularly if the work is done during freezing weather.

An interesting condition was observed on this Denver work. The roundhouse was started by a contractor, and afterward taken over by the railway company and completed by day's labor. The masons were instructed to fill every joint completely with mortar, but being so used to slighting joints that could not be seen, it was found necessary to discharge at least a dozen, one after the other, before they would do perfect work, although they had been told that they would be paid their regular $4.50 per day, whether they laid one or fifty stones, provided they laid every stone right and filled every joint perfectly.

Mr. Stern. EUGENE W. STERN, M. AM. SOC. C. E.—While the laboratory tests of Messrs. Matthews and Watson may go to show that, in the long run, the strength of concrete is not decreased materially by being moderately frozen, still there are a number of important factors in the actual execution of work which must be considered. As illustrations, some examples in the speaker's experience are worth mentioning.

In one case a reinforced concrete floor was put down in February, during freezing weather. The floor construction consisted of girders of about 22 ft. span, spaced 7 ft. apart, the floor slab being 5 in. thick. The workmanship and materials were first-class, the work being done by skilful workmen in charge of a foreman who had had extensive experience in work of this class. The work was covered with tarpaulins at night, but these precautions were not sufficient to prevent freezing. The forms were removed in May. A few days later a large section of the floor sagged about 8 in., and had to be removed and rebuilt. It might be argued that the forms were removed too soon; doubtless, if they had been allowed to remain several months longer, the floor might have thawed out and thoroughly hardened, and might have been nearly up to its full strength. It was difficult, however, to know whether any frost was left in the girders; they looked satisfactory, and, besides, the building had to be finished on time—the owner could not wait—so the contractor took a chance. No chances should have been taken, however, but every precaution should have been adopted to prevent the work from freezing.

Another example of the bad effects in concrete caused by freezing occurred in the floor slabs of a steel constructed building, in which the

steel beams were spaced about 6 ft. apart. The reinforced concrete floor slabs were put down during the winter and froze, and it took six months for the floor to dry out thoroughly, during which time water was constantly dripping from it. This was a great nuisance, as the ceiling could not be properly finished until this drying out was completed, causing serious delay in the completion of the building. Mr. Stern.

Still another case: A concrete foundation was put in for a large machine tool during the winter, and, although immediately covered with manure and hay, it froze. In the spring it commenced to thaw out. The surface was badly affected by the acid in the manure, and the work heaved up just as the ground does when the frost comes out of it. As it was not possible to wait until all the frost had come out of the concrete, because the tool had to be put in operation, it became necessary to scoop out the old concrete and rebuild the foundations.

From his experience, the speaker believes that it is unwise to take any chances in allowing concrete to freeze, and that it pays to take every precaution to prevent this from happening.

Edwin Duryea, Jr., M. Am. Soc. C. E. (by letter).—In 1885, on the first construction work on which the writer was ever employed, he became familiar with the laying of masonry in freezing weather in its most extreme form, bridge masonry being laid successfully at temperatures as low as —20° (20° below zero) Fahr. This experience seems worthy of record in the *Transactions* of the Society, especially because in a mention of this work by Alfred Noble, Past-President, Am. Soc. C. E.,* by a typographical error the minus sign was omitted and the temperature was printed merely as 20° Fahr., or 40° warmer than the actual temperature, and was so copied in an Abstract in the *Minutes of Proceedings* of the Institution of Civil Engineers of Great Britain. Mr. Duryea.

The work referred to was the construction of the Northern Pacific Railroad bridge over St. Louis Bay, at Duluth, Minn. The bridge (still in use) is a wooden pile-bent, stringer-span structure, about 5 600 ft. in length, including two swinging draw-spans and one fixed span, the three spans resting on seven masonry piers with pile foundations. Piers Nos. 1, 2, 3, and 4 were built early in 1885 and Piers Nos. 5, 6, and 7 during the following summer. This description has to do with Piers Nos. 1 to 4 only.

The masonry records were kept by the writer, and, from a report made by him at the time, the following facts and conditions are abstracted:

Dates of Laying Masonry.—

Pier No. 1	February	2– 7,	inclusive,	1885
" " 2	"	12–17,	"	"
" " 3	"	19–27,	"	"
" " 4	February	28–March 5,	"	"

* *Transactions*, Am. Soc. C. E., Vol. XVI, p. 80.

Mr. Duryea. *Temperatures During Laying.*—"During the building of Piers Nos. 1 and 2, the temperature, while the work was going on, varied from —20° Fahr. to about 0° Fahr.; when Pier No. 3 was built, from —10° to +10°; and during the construction of Pier No. 4, it was about +30°."

Mortar Used.—

For face stones..... 1 cement : 1½ sand.
" backing..... 1 " : 2½ "

The cement used was Alsen's German Portland, and the mortar was proportioned by "packed volumes" of cement (the volume or contents of the cement barrel being taken as unity).

"Throughout the whole work the sand was warmed before using by a fire beneath it, and salt was always used in the mortar." The water was not warmed, being dipped from the bay through a hole in the ice, and the stones were not wet. The composition of one "batch" of cement was as follows:

1 bbl. cement.
1½ or 2½ bbl. sand.
2 shovels salt.
10 pails water (about).

The piers were small, with the following dimensions at the top of the shaft, under the belting course:

Pier No. 1 ..... 7 by 27 ft.
" " 2 ..... 8 " 28 "
" " 3 turn-table pier..... .....26 ft. in diameter.
" " 4 ..... 7 by 27 ft.

The volumes of masonry in the piers, to the nearest cubic yard, are given in Table 2.

TABLE 2.

Pier No.	Cubic Yards of Masonry.				Total Masonry, in Cubic Yards.
	Facing.	Backing.	Coping.	Parapet.	
1	125	27	18	....	169
2	120	34	21	7	182
3	149	169	46	....	363
4	113	19	18	4	155
Totals....	507	249	102	11	869

The total quantity of cement used on the four piers was 365½ bbl., including 8¾ bbl. for doweling. The total quantity of salt used was 14¾ bbl. The constituents per cubic yard of masonry are given in Table 3.

TABLE 3.

Mr. Duryea.

Pier No.	Cement per cubic yard of masonry.	Backing masonry per cubic yard of face masonry.
1	0.33 bbl.	0.19 cu. yd.
2	0.38 "	0.23 "
3	0.47 "	0.87 "
4	0.38 "	0.14 "
Totals.....	0.41 bbl.	0.40 cu. yd.

The stone used was a reddish limestone from Mankato, Minn., except that in the coping of Pier No. 3 (the turn-table pier) the ring stones and the center stone were of granite, also the ring stones of the footing course. Granite was used in the footing course, however, only because the stones had been left over from another bridge.

The beds of the face stones and their joints were cut for $\frac{3}{8}$ in. thickness, and were so laid. Much annoyance was caused by the thinness of the beds, and in Piers Nos. 5, 6, and 7, built during the following summer, the beds and joints were made $\frac{1}{2}$ in. thick. The backing stones were cut to beds (about 1 in.), but their sides were not cut to joints, the cavities between them being filled with chunks and spalls bedded in mortar.

The masonry was built by contract (the railroad company furnishing the cement), and a careful inspector was on the masonry constantly during its laying. Many stones had to be raised because the beds were too thick or because the bearing was uneven, and in the colder portion of the time, when Piers Nos. 1 to 3 were laid, the mortar bed was always found frozen to the stone above or below in a solid sheet of ice. It is doubtful if any of this mortar set before freezing, but, notwithstanding this, when the face joints and beds were "pointed," during the following summer, the mortar had to be chiseled out of the joints, and brought with it many small flakes of stone.

This work has been described thus fully because of the extremely cold weather in which the masonry was laid (it was much colder at night than the minimum temperature of —20° Fahr. mentioned), and because of the severe and long-continued test of nearly 24 years to which these light piers have been subjected without developing any defects. The writer has not seen the piers since 1885, but in correspondence about five years later was informed that they were in perfect condition, with about 75 trains crossing the bridge daily. Twice since then (the last time about five years ago) he has been informed by E. J. Pearson, M. Am. Soc. C. E., then Chief Engineer of the Northern Pacific Railroad, that the bridge was still in full use

Mr. Duryea. and the masonry in excellent condition. Only a few months ago he ascertained from a resident of Duluth that this condition apparently still continues.

The bridge was built under the general supervision of Mr. Noble, who was then Principal Assistant Engineer, in charge of bridge construction, and under the immediate direction of the late E. H. Beckler, M. Am. Soc. C. E. Mr. Beckler's principal assistants on the work were M. A. Waldo, M. Am. Soc. C. E., and the writer.

Four years later, in 1889, the writer was connected with another piece of masonry, placed in freezing weather, which did not prove so successful. This work (also under Mr. Noble) was the concrete in the foundations of a number of cylinder piers in the Kentucky approach to the Cairo Bridge. The concrete was placed by contract, under the constant attention of a good inspector, with such precautions as warming the sand and water, adding salt, etc. However, Louisville (natural) cement was used instead of Portland, and the concrete never hardened properly. It was finally removed and replaced by better concrete during the following summer. The winter temperatures at Cairo, of course, are much higher than those of Duluth.

Several times since the writer has been employed on masonry laid in freezing weather. On the New Croton Aqueduct dams (on three of which the writer was the contractor's engineer or superintendent) the Commission allowed no masonry to be laid when the temperature was below +22° Fahr. (10° below freezing point); and during the winter required the sand to be warmed, salt to be used in the mortar, only Portland cement to be used, and each stone to be steamed (instead of being wet with water, as was done during other parts of the year) just before lowering it to its mortar bed. Excellent masonry of course resulted.

In the construction of the Williamsburg Bridge, New York City, on which the writer was engaged as Resident Engineer in charge of the Brooklyn Tower Foundations and Anchorage, no interruption was ever made to the laying of masonry or concrete in freezing weather, except that due to the workmen preferring not to work when the weather was very cold or stormy.

The general conclusion seems warranted that by using proper precautions (which are also entirely practicable) masonry may be laid with perfect safety during even the coldest weather; also that the use of natural cement in freezing weather involves much more risk than the use of Portland cement—probably in most instances a greater additional risk than is justified by the relatively small saving which may result.

Mr. Lewis. Myron H. Lewis, Esq. (by letter).—It would seem that the authors made no experiments on the effect of freezing by using the materials just as they were, that is, the cement and sand at winter temperatures,

and the water near 32° Fahr., the briquettes being allowed to set entirely in air at low temperature. It would certainly be useful to know what results could be obtained in the laboratory with cement mortar, made without any special treatment, and setting under the conditions of ordinary practice, and such experiments should supplement those made by the authors, if the full benefits are to be derived from them. Mr. Lewis.

Mr. Stern, in discussing the effect of freezing and thawing on the concrete in a certain building, stated that it took nearly 3 months to get the work properly dried out. In European cities, there are a number of artificial drying apparatus, especially adapted to dry rapidly the walls and floors of new buildings. By the use of such apparatus the work referred to could have been dried out in perhaps a week. Fig. 1 shows one of the forms now being introduced in the United States. The drying is accomplished by a constant supply of highly heated fresh air in circulation, induced by the arrangement of the fresh air inlet and heating pipes shown in Fig. 2. Coke fuel is used.

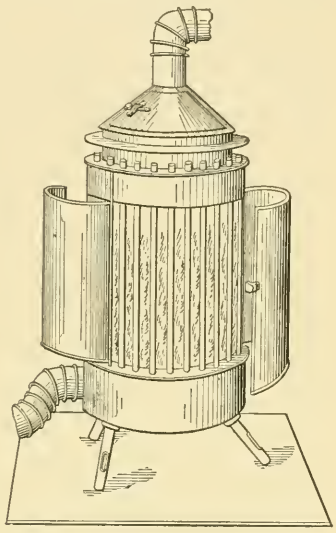


FIG. 1.

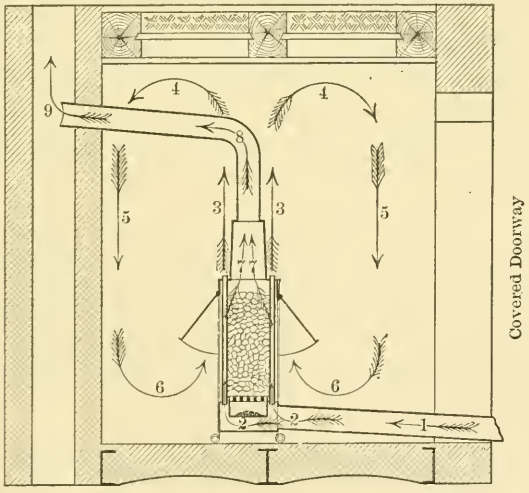


FIG. 2.

Mr. Lewis. The cost of drying out an ordinary residence is from $2.50 to $3.00 per room, and the drying can be effected in a few days. The interior finish of buildings can be greatly hastened during the wet season by artificial drying methods of this kind.

Mr. Belzner. THEODORE BELZNER, JUN. AM. SOC. C. E. (by letter).—During the construction of the concrete piers for the elevated portion of the New York Subway, in the winter of 1904, the writer examined some which had been put in during freezing weather. In a number of cases the concrete was frozen, and apparently had not set; this was evident from the fact that it broke when the wooden forms were removed, portions of it adhering to the forms. Other and similar tests were made to establish this fact, and, finally, the matter was brought to the attention of the Engineer-in-Charge. Upon consideration he decided that the forms should be replaced around the piers already built, that the excavation should then be back-filled, and the top surface of the concrete covered with plenty of manure, and should remain in this condition until such time as examination showed that the concrete had begun to set.

It was also decided that, in other concrete laid during freezing weather, the sand and gravel were to be heated, the wooden forms were to be left around the piers, and be protected with manure immediately after the concreting was completed, and until it had begun to set.

Upon later examination of some of these piers, the writer found that the concrete had set and was in first-class condition, indicating that the precautions taken had protected it to a great extent from frost.

The writer has known of many cases where concrete, deposited in freezing weather, has given good and also bad results, and he firmly believes that if it can be kept in a favorable condition with regard to temperature, while it is setting, good results can be obtained.

Messrs. Matthews and Watson. MESSRS. ERNEST R. MATTHEWS AND JAMES WATSON (by letter).—The writers are pleased to know that this paper has been so heartily received, and that the experiments described have been so much appreciated.

Mr. Davis thinks the tests should have been carried on for at least 3 months. The writers agree with him, but the time and place were against them, as they could not, without causing inconvenience, have retained the use of the cold storage chamber for a longer period, and, for comparative tests such as these, any differences in strength are sufficiently distinctive at the end of 28 days to enable conclusions to be drawn, and to show the practical limitations in constructional work.

Mr. Stern, from his practical experience, shows the weakness of concrete which had been placed in a floor span between iron girders and had frozen before it had set. One of the writers has had experi-

Messrs. Matthews and Watson.

ence also with concrete foundations, made of coke breeze, sand, and cement, which were frozen through within 8 hours of being laid in position and had not set properly until some 14 days afterward. Tests made by the writers show that the initial set of the cement mortar must take place before the mass is frozen, otherwise a retardation of strength occurs, and the mortar remains soft for some days after thawing has begun. Tests made by them with cement mortar gauged with a normal quantity of water, allowed to set for 24 hours, and then frozen for 6 days, show on analysis that combination was retarded, the uncombined being considerably in excess of the combined water.

While agreeing with the other discussors that, by taking due precautions, concrete can be used in the coldest weather, still it is well to remember that the addition of salt, even in small quantities, lowers the tensile and compressive strength of the mortar; and, in calculating the stresses and strains to be incurred, due allowance should be made. Although in Great Britain the temperatures are not as low, nor do they continue for such a long time, as in the United States, still it is necessary, where concrete work is urgently needed in cold weather, not only to warm the aggregates before using, but also to provide some heating arrangement whereby the temperature of the surrounding atmosphere can be kept as near 60° Fahr., as possible, so that good progress may be made with the work, otherwise there is a risk of reliable workmanship being spoilt by the sections not bonding together properly.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1113

SAMPITTIC SURFACING.*

By Walter Wilson Crosby, M. Am. Soc. C. E.

With Discussion by Messrs. L. W. Page, Prevost Hubbard, Arthur H. Blanchard, Philip P. Sharples, H. W. Clark, C. E. Grunsky, Henry B. Drowne, Francis P. Smith, J. W. Howard, Clifford Richardson, and Walter Wilson Crosby.

For several years the writer has been studying the uses (and results) of hydrocarbon compounds in road making, and has been impressed with the lack of standards by which to judge the various so-called "bituminous cements" offered for sale, as well as with the pressing need for such standardization. With the increased use of this cement has come the inevitable increase in the variety of trade compounds; moreover, with the change in traffic conditions, highway engineers tend to conclude that the need for such a proper cement, and its future use, are greatly increased.

The writer, from personal inspection, is familiar with most instances of the use of hydrocarbon cements in road building in the Eastern States, and thinks it will not be disputed that cements of considerable variety have been used, and many differing results have been secured.

Under different conditions, occasionally, similar results have occurred; and, under similar conditions, varying effects have been obtained. Analyses of the causes for these variations seem to indicate that differences in the hydrocarbon compounds used are the main

* Gr., psammos, sand; pitta, pitch. Paper presented at the meeting of April 21st, 1909.

sources of variation, and that, if proper standardization of the cement material could be secured, one might hope for uniformity of results. To this end, the writer, for more than a year, has been conducting a search for information concerning the composition, from the standpoint of the highway engineer, of the hydrocarbon compounds available, and the effects, when used on the road, of certain constituents known to exist. He regrets to report a woeful lack of published information on the subject, this, apparently, being due to the complexity of the compounds dealt with, and the unscientific way in which many who are most familiar with the use of the material in question have made and recorded their experiments. The results attained by the writer are far from perfect, on account of the limited time at his disposal for this work, and, quite likely, his limited abilities in this direction. He hopes, however, that by directing attention anew to the subject, and possibly by furnishing a concrete starting point for further work, his efforts will not have been in vain.

It will be recalled that, not so many years ago, it was the custom to specify cement of a particular brand, or cement which, in the opinion of the engineer, was equal to the product of a certain named firm. To-day lime cement is a standardized article, and such specifications would be looked upon with contempt.

Is it more than fair to hope that the standardization of bituminous cements may follow shortly; and to believe that, not only is it possible that within a few years the engineering profession will be relieved of criticism for such specifications as "Borrowin's Pilgrim Brand Joint Filler," "Rotto Asphalt," "Stickulithic Processes," or "equally good" thereto?

The specifications for "Sampittic Surfacing," offered herewith, may be used as a starting point for discussion, principally because it seems to the writer that the simplest form of the use of a hydrocarbon cement is thus presented.

Further, it seems possible that, if a proper standardizing of a base is secured, modifications or solutions of this base, required under different conditions and for different purposes, may easily be made by simple changes in the inserted figures, as the necessity may dictate.

The writer will gladly welcome discussion of the foregoing, and of the specifications appended, especially those clauses relating to the "Pitch Compound."

Specifications.

Sampittic Surfacing.

281.—Sampittic surfacing shall be used wherever provided for in the plans or directed by the Engineer. The width and thickness required at different points shall be those shown on the plans, or designated by the Engineer.

282.—This sampittic surfacing will usually consist of one 6-in. course of a thorough mixture of pitch and sandy soil, to be formed on the roadbed after the latter has been properly graded and shaped.

Roadbed Material.

283.—The roadbed for the sampittic surfacing shall consist of the natural sandy roadbed, prepared and shaped as shown on the plans. Where the natural roadbed is found, during the work, to consist of material which, in the opinion of the Engineer, is unfit for this form of construction, the Contractor shall remove as much of this unfit material as may be deemed necessary by the Engineer and shall replace it with sandy material which, in the opinion of the Engineer, is suitable for the purpose. All unfit material thus removed will be measured and paid for as "Excavation."

Cuts and Fills.

284.—In cuts and fills, unless otherwise specially directed, the roadbed shall be graded to a width of —— feet, and shall be free from spongy and vegetable matter, roots, and stumps. The portion of the roadbed prepared for the pitch surfacing shall be —— feet wide, and shall be brought to the grades and cross-sections shown on the plans. The fills shall be —— feet wide on top.

Old Earth Roadbed.

285.—Where no change from the present grade of those portions of the road, not already surfaced, is shown on the profile, the roadbed shall be shaped to the proper cross-section; and slight elevations, with contiguous depressions, shall be removed, so as to form an even and smooth surface.

Shape.

286.—The shape of the finished road shall be that shown on the accompanying plans, and shall have a cross-slope of —— inches to one foot.

Pitch Compound.

287.—The pitch compound to be used shall be a hydrocarbon, refined from tar or petroleum, or made from natural asphaltic pitches by the use of a proper solvent or flux.

It shall be uniform in character, and shall possess the following characteristics:

a. The percentage of free carbon shall not exceed ten.

b. The percentage of fixed carbon shall not exceed twenty.

c. The percentage of paraffin shall not exceed two.

d. When 20 grammes of the material are heated on a flat-bottomed dish, 2¼ in. in diameter, for 24 hours, in an oven, the interior of which is maintained at a uniform and constant temperature of 105° cent., the loss shall not be more than 15 per cent.

e. A sample of the pitch compound proposed to be furnished will be evaporated until it has been hardened to show a penetration, by the Dow machine, of 50 cm. at 25° cent. This pitch must show a ductility, by the Dow machine, greater than 50 cm. at 25° cent., and greater than 10 cm. at 10° cent.

f. When an amount equal to one-half the percentage of loss, under the requirements of Clause *d,* shall have been distilled from the normal pitch compound, the residue shall show a consistency of not more than 40 cm. at 35° cent.

g. The consistency of the pitch compound for this work shall be such that 50 cu. cm., at a temperature of 100° cent., will flow through an Engler instrument in not more than 75 sec.

h. When the pitch compound proposed to be used shall have been evaporated to a consistency which will show a penetration of 50 cm. at 25° cent., the percentage of this residue to the whole sample of normal pitch compound shall be not less than 60.

i. The melting point of this residue shall be not less than 65° nor more than 85° cent.

j. The pitch compound proposed to be used shall contain no constituents which can be removed by distilling it up to 170° cent., nor more than 20% by distillation between 170° and 270° cent.

k. All pitch compounds must be free from dirt or adventitious matter in excess of 2% of the compound in its normal state.

l. Pitch compounds which, in the opinion of the Engineer, have

offensive characteristics, by reason of their odor or otherwise, will not be accepted.

m. Each lot of pitch compound furnished under this contract will be subject to the tests mentioned, and shall show by these tests the characteristics specified. The tests will be made on samples taken from each lot as it arrives, and the results of the tests on the samples will be considered as characteristic of the lots from which the samples were taken. The rejection of a sample for any reason will cause the rejection of the lot from which the sample was taken. The samples will be taken, by the gallon, from tank cars, by the Engineer or his authorized assistant. If the pitch compound is delivered in barrels, a pint will be taken from each of eight barrels selected at random by the Engineer from each carload of the shipment, and these pints will be thoroughly mixed together to form the sample to be tested.

288.—All pitch compounds, as well as all other materials, used under this contract, shall be subject to the approval of the Engineer, and pitch or other material disapproved by him shall not be used. Any disapproved material shall be removed promptly and replaced by approved material, by and at the expense of the Contractor, on notice to him from the Engineer.

Spreading and Mixing.

289.—When the roadbed, after being prepared and shaped as herein described, does not consist of material in a finely divided state to a depth of at least 6 in., if deemed necessary by the Engineer, it shall be put in such condition by thoroughly plowing, harrowing, and cultivating to a depth of at least 6 in.

290.—On the roadbed, prepared as herein described, the pitch compound shall be spread uniformly by using a sprinkling cart of a pattern approved by the Engineer, or by such other means as may be so approved, and in a quantity not less than 1 gal. nor more than 1½ gal. per sq. yd. of surfacing. Unless otherwise approved in writing by the Engineer, the pitch compound shall be heated to a temperature of not more than 150° cent., and applied at a temperature of not less than 80° cent.

291.—Immediately after an application of pitch compound has been made to a section of road, as above described, the pitched material shall be thoroughly turned over with plows or harrows and mixed so

that none of the unmixed pitch is visible on the surface. A second application of pitch compound shall then be made, as before. The pitched material shall then be mixed thoroughly by the use of plows, harrows, road scrapers, and such other means as may be necessary to insure a complete, uniform, and thorough mixing of the pitch compound and the sandy material of the roadbed. To secure this result, additional pitch compound shall be supplied, where necessary, by the Contractor, in the manner and under the conditions above described. Uniformity of mixing is most important, and must be secured, and pockets of unusually sandy or excessively pitchy material will not be permitted. When finally the roadbed material is mixed satisfactorily, in the opinion of the Engineer, the surface shall be carefully shaped, by raking or otherwise, to the cross-section, grades, etc., shown on the plans, due allowance being made for settlement.

Rolling.

292.—The pitched material shall then be rolled by a "tamping roller" of a pattern approved by the Engineer. This roller shall have toothed concentric rings, or shall be a drum studded with spikes, or shall be of a design which will insure the thorough compaction of the pitched material from the bottom up. The rolling shall be continued until the utmost degree of compaction is secured, and until the spikes or teeth of the wheels do not penetrate the surface more than 2 in. During the rolling, and if deemed necessary by the Engineer, the road shall be sprinkled with sufficient water to insure the thorough compaction of the surfacing.

Finishing Coat.

293.—When, in the opinion of the Engineer, the pitched material shall have been sufficiently compacted, as above described, a third coat of pitch compound shall be applied, as hereinbefore described, and in a quantity not less than ½ gal., nor more than 1 gal., per sq. yd. The surface shall then be lightly harrowed or raked, or both, to insure a thorough mixing of the pitch compound with the loose material remaining in the road, and shall be raked and trimmed to the cross-section and grades desired. The road shall then be thoroughly rolled, until firm and hard, with an ordinary steam roller, weighing not less than 5 tons. Any unevenness or depression shall be remedied by the addi-

tion of properly mixed pitch compound and sandy material of a character similar to that in the roadbed, as may be deemed necessary by the Engineer. Should spots in the road show an excess of pitch under this last rolling, sufficient sandy material to absorb the pitch shall be dusted over them carefully and evenly.

Price.

294.—The price agreed to be paid for pitch surfacing will include all labor and material necessary to do the work herein specified under pitch surfacing, and will also include the repairs necessary, in the opinion of the Engineer, for a period of two months from the day of the acceptance of the work, which repairs shall be made with the same materials and in the same manner as the construction above specified.

DISCUSSION

L. W. PAGE, ESQ.* (by letter).—While the writer is in hearty accord with the growing desire exhibited by road engineers to obtain standard specifications for bituminous cements to be used in road treatment, and while he realizes to the fullest extent the benefits which would be derived from such specifications could they be produced, there are certain points which are apt to be overlooked by the engineer and should receive serious consideration. Mr. Page.

In the first place, local conditions, such as climate, location of the road, quantity and character of the traffic to which the road is subjected, as well as the character of the road material, have such an important bearing on the requisite characteristics of a bituminous binder that even when the same methods of construction and application are followed, it is doubtful if any one cement will prove equally satisfactory for all cases. In many instances experiment alone will determine what binder is best suited to meet given conditions, and the impracticability of following the same strict specifications for all cases, therefore, is apparent.

Broad specifications in regard to the elimination of certain objectionable properties which have invariably produced bad results, and favoring those characteristics which are essentially necessary to a good binding material, can be framed, of course, but strict limitations with respect to certain constituents, such as free carbon, fixed carbon, paraffin contents, etc., are, at the present time, based on matters of personal opinion rather than on established facts. This is particularly true of country roads, as considered apart from city pavements, and is largely due to two facts: (1) That, owing to necessarily less refined methods of construction and less severe traffic conditions, binders which would be of little service for city work will often prove satisfactory for country highway work; (2) that, at the present time, there are but few reliable data as to the characteristics of the binders which have been used in experimental work, and their effect on the results obtained.

From a careful consideration of this subject, the writer is led to the conclusion that the framing of specifications for bituminous road binders is, and will be for many years to come, a matter of expert opinion for individual cases, and that, in view of the fact that the near future will see an immense amount of bituminous road work carried on, every progressive road engineer should make a study of bituminous road binders, and, in all reports of experimental work, should include the results of an examination of the binder which he has used. By so doing, any binder which has met his requirements

* Director of Public Roads, Washington, D. C.

Mr. Page. in a satisfactory manner can be identified, and specifications can be made which will enable him to obtain a like material again and duplicate his results. His experience will also be of considerable value to others who are working along similar lines.

In regard to Mr. Crosby's proposed pitch compound, it might be said that, while there is little doubt that under certain conditions a material meeting his specifications would prove satisfactory, it is questionable whether such a guaranteed material could be generally obtained at anything like a reasonable cost. The time required to make an examination covering these specifications is another objectionable feature. It might be added that, while Section 287 states that "the pitch compound to be used shall be a hydrocarbon, refined from tar or petroleum, or made from natural asphaltic pitches by the use of a proper solvent or flux," according to the writer's experience, practically all gas-house tar pitches are eliminated by Clause *a*, and even coke-oven and water-gas tar pitches by Clause *j*.

According to the writer's belief, any ductility test made as described in Clause *e* is of little or no service in determining the road-binding value of the original material, for the reason that, when subjected to temperatures sufficiently high to give a residue of the consistency stated, many oils are so altered that the residue thus artificially produced in no way represents the binding value of the original material.

Mr. Hubbard. PREVOST HUBBARD, ESQ.* (by letter).—Before discussing Mr. Crosby's specifications for a basic pitch compound, the writer wishes to state that his views relative to the practicability, or rather the impracticability, of framing strict specifications which will meet all conditions satisfactorily are in close agreement with those presented by Mr. Page.

Considered from a chemical standpoint alone, the wide differences in composition existing between the two classes of bituminous binders —tars and asphaltic oils—make it a difficult matter to deal with both in one set of specifications. This can readily be shown by taking up the various clauses separately and determining their value as applied to each class of binders. By so doing, a number of interesting facts pointing toward the most rational methods of examination for each class may also be developed. As a consideration of this subject in detail, however, would constitute a paper by itself, only those points which the writer believes to be most important will be included in the following brief discussion.

Clause a.—From the examination of a considerable variety of bituminous road binders in the Laboratory of the United States Office of Public Roads, it would seem that any specification limiting the percentage of free carbon to 10 is applicable to tars only. A total bitumen

* Assistant Chemist, Office of Public Roads, U. S. Dept. of Agriculture.

clause could be substituted for oils, and while the two determinations are made in much the same way, the amount of material insoluble in carbon bisulphide could be limited to 2% for most asphaltic oil products. In cases where a material such as Trinidad asphalt had been fluxed with an oil to produce the pitch compound, however, allowance would have to be made for a considerable amount of inorganic material which, of course, would be insoluble in carbon bisulphide. As applied to tars, a clause limiting the free carbon contents to 10% would bar out practically all gas-house coal-tars, and, while the writer firmly believes in the superiority of low free-carbon tars, it would seem hardly fair to eliminate those containing more than 10%, as this class constitutes a large proportion of the tars produced in the United States, and, in some instances, good results have attended their use in road construction. Mr. Hubbard.

Clause b.—A determination of fixed carbon in a bituminous road binder is of value mainly for the purpose of determining the mechanical stability of the bitumens present. As this property, within certain limits, is believed to be almost directly proportional to the percentage of fixed carbon, it would seem that if any limitation is made it should be in the other direction, that is, the lowest limit should be stated rather than the highest. When applied to the bitumen itself, it is extremely doubtful if any ordinary pitch compound would show fixed carbon as high as 20%, and, if it showed as high as 15%, it could hardly be expected to meet the requirements of Clause *g*. In addition, it might be said that while an oil or asphaltic product with fixed carbon running as high as 7% might be satisfactory for construction work, the same would not necessarily be true of a tar pitch, even if the free carbon content were not considered. A fixed-carbon specification, therefore, would seem to be of value mainly as applied to oil and asphaltic products, in the manner indicated.

Clause c.—As there is considerable difference of opinion among chemists, at the present time, as to the value of a paraffin determination applied to road oils, the writer will not consider it in detail. It might be stated, however, that, without question, such a determination is unnecessary in the examination of tars. The writer also believes that, as a rule, it is unnecessary in the examination of oils, as the characteristics of the base obtained from a volatilization test will show whether paraffin hydrocarbons are present in sufficient quantity to injure the material for road use.

Clause d.—The main objection to this clause is that a 24-hour continuous volatilization test at a temperature of 105° cent., is impracticable for most laboratories.

Clause e.—While no criticism of a ductility test, if it can be made on the original material, is here intended, it would seem to be of little or no value as applied to residues produced at high tempera-

Mr. Hubbard.

tures, for the reason that in producing such residues many bituminous materials are chemically altered in such a way that a ductility test made in the manner described cannot be depended on to represent the characteristics of the original material. This can often be shown by a comparison of the relative fixed carbon, naphtha insoluble, and carbon tetrachloride insoluble determinations made upon the original materials and the residue.

Clause f.—This clause will not be discussed, owing to its direct relation to Clause *d*, which has already been considered.

Clauses g, h, and i.—A determination of viscosity and melting point is undoubtedly of considerable value when it is desired to apply a material in a given manner and under given conditions; but the writer believes that a determination of the consistency of a residue resulting from a volatilization test made at comparatively low temperatures, say, 163° or 205° cent., is of more service than that of the percentage of residue of given consistency which can be produced at high temperatures. The reasons for this are the same as those mentioned under Clause *e*.

Clause j.—While this specification might be applied to oil products, it would bar out practically all tar preparations which, as a rule, contain considerably more than 20% of oils which can be removed by distilling between 170° and 270° cent.

Clause k.—The only criticisms applicable to this clause have been made evident in the discussion of Clause *a*.

Clauses l and m.—These clauses would seem to be applicable and necessary to any set of specifications, but it should be remembered that under ordinary conditions where a carload of material is to be held up until an examination can be made, a very limited time can be allowed for such an examination. From this point of view, alone, it is evident that an examination, according to Mr. Crosby's proposed specifications, requires entirely too much time to be practicable.

Conclusions.—In general it would seem inadvisable to attempt to frame specifications for bituminous road binders, except for individual cases. Somewhat different methods of examination are required for asphaltic oil products and tar products. Owing to the fact that no standard methods of examination have as yet been established for these materials, reports from different chemists upon the same material are apt to differ greatly. The establishment of standard methods of examination, therefore, should receive first consideration; otherwise, exact descriptions of the methods which should be followed will have to be included in each set of specifications. Owing to lack of detailed data as to the exact effect of composition upon the results obtained in practice, an examination of bituminous road binders is mainly of value as a means of identification and for the purpose of determining which of a number of materials is best adapted to meet given condi-

tions. Strict specifications, therefore, cannot be made satisfactorily until such data are available. In future experimental work with bituminous road binders, therefore, it is recommended that the results of an examination of the binder be included in any report which may be made. Mr. Hubbard.

ARTHUR H. BLANCHARD, M. AM. SOC. C. E.—Highway engineers owe Mr. Crosby a debt of gratitude for presenting for criticism, tentative specifications covering pitch compounds, and thus precipitating a discussion of bituminous materials in its entirety. Mr. Blanchard.

The present status of specifications covering bituminous materials is unsatisfactory from the standpoint of both the producer and the purchaser, and is due primarily to a lack of knowledge of the methods of specifying the requisite properties, and to the insufficiency of published data relative to the results attained by using various bituminous materials in divers ways.

Without doubt, every highway engineer dealing with the construction and maintenance of roads subjected to excessive motor-car traffic will welcome enthusiastically the adoption of standard specifications which will permit of calling for bids for a bituminous binder, with the expectation that the material submitted will be adapted to the exigency. The attainment of this desideratum will take from two to five years of co-operative work on the part of chemists and of the highway engineers who have charge of the construction and maintenance of bituminous surfaces.

One method of procedure which would result in the acquisition of the desired data in the near future is as follows: First, keep full notes during construction, covering the points mentioned below; second, make a complete chemical and physical analysis of the bituminous material in accordance with standard methods; and third, keep a complete record of the condition of the road under varying climatic conditions. By compilation and a comparison of the data acquired it will be possible, finally, to determine the essential requisites for bituminous material to be used in any particular method of construction, and the requirements which must be included in specifications in order to secure materials which possess these properties.

The essential data to be recorded covering the construction of bituminous surfaces are as follows:

ROAD PRESERVATION.

Data Relative to Construction.—
State
County.
Town.
Name of highway.
Class of highway.*

* See *Transactions*, Am. Soc. C. E., Vol. LXI, p. 446.

Mr. Blanchard.

Nature of traffic.*
Traffic census.†
Distance to nearest railroad station.
Distance to source of materials.
Length.
Width.
Area, in square yards.
Nature of subgrade.
Maximum depth and length of fill.
Maximum, mean, and minimum grades.
Kind of stone, gravel or sand used.
Sizes or grades of broken stone or gravel.
Contractor.
Dates when construction was commenced and completed, or months during which construction was carried on.
Temperatures at 8 A. M. and 2 P. M. on each day during construction.
Climatic conditions on working days.
Location of car tracks, if any, relative to bituminous surface.
Road exposed or protected.
Number of hours in legal working day.
Average rate of progress per day, in square yards.
Specifications covering construction of bituminous surface.
Details of construction.
Data relative to contract covering the construction of the road complete.
- Bituminous material furnished by contractor, or by party of the first part.
- Cost of bituminous material per square yard, if furnished by party of the first part.
- Cost per square yard complete.
- Estimated cost per square yard over and above cost of similar construction minus bituminous material.

Data relative to contract covering the construction of the bituminous surface as a secondary contract.
- Lump sum contract, or price per square yard.
  - Bituminous material furnished by contractor, or by party of the first part.
  - Cost of bituminous material per square yard, if furnished by party of the first part.
  - Cost per square yard of bituminous surface complete.
- Day labor plus percentage contract.
  - Bituminous material furnished by contractor, or by party of the first part.
  - Cost of bituminous material per square yard, if furnished by party of the first part.
  - Cost per square yard of bituminous surface, complete.
  - Rebate on watering cart, labor, screenings, etc.
  - Percentage allowed on extra work.

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* See *Transactions*, Am. Soc. C. E., Vol. LXI, p. 446.

† See *Engineering News*, Vol. 61, p. 466.

Mr. Blanchard.

Unit prices (hour basis).
Common laborer.
Foreman.
Man capable of handling bituminous material.
Double team.
Single team.
Rental of mixing plant, kettles, and accessories, distributor, or other special apparatus.
Roller.
Watering cart.
Scarifier.

Every effort should be made within the next two months to standardize methods of determining chemical and physical properties, in order to obtain the maximum amount of information from the construction work of 1909.

In the laboratory of the State Board of Public Roads of Rhode Island, tests are made to determine the following properties in accordance with methods adopted by Mr. Crosby and the writer:

Tars.—
Water-soluble materials.
Specific gravity.
Free carbon.
Fixed carbon.
Loss by evaporation for 21 hours at 105° cent.
Penetration of residue.
Melting point of residue.
Loss by distillation.
Viscosity.

Asphalts and Asphaltic Oils.—
Melting point of solid asphalts.
Penetration of solid asphalts.
Water-soluble materials.
Specific gravity.
Free carbon.
Fixed carbon.
Paraffin.
Loss by evaporation for 7 hours at 170° cent.
Loss by evaporation for 21 hours at 105° cent.
Penetration of residue.
Melting point of residue.
Loss by evaporation for 21 hours at 225° cent.
Penetration of residue.
Melting point of residue.
Solubility in 88° Baumé naphtha.
Viscosity.

Other tests which are made in the Rhode Island laboratory are for the determination of the cohesive strength of the material under gradually applied tension, and the cohesive strength under impact.

Mr. Blanchard. The machines used in the Rhode Island laboratory for testing the cohesive strength of bituminous materials were designed by Henry B. Drowne, Assoc. M. Am. Soc. C. E., Assistant Engineer, State Board of Public Roads, and he will describe these machines and the methods of conducting the tests.

The object of the cohesion tests is to acquire information relative to the comparative value of various bituminous materials from the standpoint of their ability to resist: first, the action of motor-car traffic on the surface layer; second, the impact of horses' hoofs; and finally, to devise specifications covering these essential properties.

In writing specifications for bituminous materials to be used in highway construction, two facts must be kept constantly in mind, if such specifications are to prove satisfactory: first, the relationship between a given requirement and the value of that property of the material when considered from the standpoint of a road binder; and second, the advisability of limiting the requirements of the specifications to those for which the tests can be made in a reasonable period.

Mr. Sharples. PHILIP P. SHARPLES, ESQ.*—In discussing the subject of tests for bituminous materials, a sharp line should be drawn between methods of analysis suitable to be inserted in a specification and those which are of scientific or academic interest. Both the consumer and the manufacturer desire that a product with certain characteristics should be defined. The tests which shall confine the product within the limits should be as simple as possible and easily executed in any works laboratory without special apparatus.

To confine this discussion to a criticism of the tests for tar materials, the specification, as set forth by Mr. Crosby in its amended form, requires far too many tests, and some of them are much more complicated than necessary. Mr. Smith has already outlined the objections to the tests, and Mr. Hubbard's discussion is along the same lines.

Mr. Crosby's specifications call for fifteen different tests. A specification calling for not more than six or seven tests should define the product with sufficient clearness. As a model, in the direction of simplicity, the specification of the Massachusetts Highway Commission for the recently advertised Milford work is to be commended for its form, although the figures are subject to modification. Mr. Clark discusses the Massachusetts specification, and a few comments are offered.

In the case of Mr. Crosby's tests, as Mr. Smith has pointed out, the free-carbon content required is too low. A definite minimum and maximum should be set. The test for evaporation loss should be modified so that it may be compassed in one working day. Equally

* Chemist, Barrett Manufacturing Company, Boston, Mass.

good results may be obtained, it is believed, by shortening the time and raising the temperature slightly. Mr. Sharples.

The viscosity test should be made on a standard instrument, and preferably should be modified so that it will indicate the viscosity at ordinary temperatures.

To conclude, the speaker believes that the following tests are sufficient to define a coal-tar pitch compound: Specific gravity; free carbon; distillation test, including tests of oils and pitches obtained. To these may be added a viscosity or penetrometer test.

H. W. Clark, Esq.*—The speaker has been very much interested in Mr. Crosby's paper, and is glad to take part in the discussion. As has been stated by the author, the paper differs, in many respects, from the form in which the speaker first saw it; that is, as now presented, the limiting figures in the specifications have been omitted. Mr. Clark.

During the past nine months the Highway Commission of Massachusetts has had under way many laboratory and road experiments on this subject, and a large number of samples have been examined chemically and submitted to physical tests. Up to the present time, about 250 analyses of tars, refined tars, asphalt oils, oil asphalts, trade compounds, etc., have been made, and, as the result of all this work, certain specifications have been drawn up in regard to tests which these road materials should pass to show certain qualities which they must possess in order to make them of value in road work. In this experimental work and in drawing up the specifications the Commission has had in mind no theoretical material which, perhaps, might be of greater value as a binder than any now on the market, such a material as probably would have to be found if all Mr. Crosby's specifications, as first presented, were held to; but, rather, an endeavor has been made to find out, from experimental roads and analyses of materials, which of these binding materials in each class has thus far, apparently, given the best results, and the specifications have been framed so that only the best of these materials, judging from chemical analyses and practical results, will pass them. It has been thought necessary and most practical to have separate specifications for refined tars, asphalt oils, oil asphalts, and natural asphalts, and in compiling these specifications the aim has been to make them as simple as possible, that is, not to make the labor of analytical chemical work and physical tests in various laboratories unduly arduous, but to include such tests as will surely, from what is known at present at least, cause the use of desirable binders.

The methods of analysis used by the Massachusetts Highway Commission differ to some extent from those outlined by Mr. Crosby. They are simpler, and it is intended to make them public soon, in

* Chemist, Massachusetts State Board of Health.

Mr. Clark. order that those submitting binding materials can know just how the laboratory work of the Commission is done. It is not necessary to enter into a discussion of these methods, however, although attention may be called to one or two points. Considerable has been said in regard to physical tests, especially in the way of suggesting that tests similar to those to which cement is subjected may be eventually developed. It has been believed from the beginning that some work of this sort was necessary, and, for the past nine months, briquettes have been made of certain proportions of sand and the bituminous materials undergoing examination, and these briquettes have been submitted to certain tests. This was started coincidently with the chemical work, as it was believed that materials proposed as binders should show some binding property, and this property can certainly be shown more quickly by physical than by chemical methods. Of course, the chemical analyses are of more importance in many respects than any physical test. The specifications which the Highway Commission has just issued, include a briquette test. In studying these briquettes, however, it is fairly evident that it does not necessarily follow that those binders which soonest produce hard and strong briquettes are the most valuable. In Mr. Crosby's paper, as first presented to the speaker, there was one specification covering the loss which the material should undergo when 20 grammes were heated in a flat-bottomed dish, etc., for a certain number of hours. In its work the Massachusetts Highway Commission has found that the various classes of materials must be differentiated in this respect, for the refined tars and asphalt oils act very differently one from another in this question of loss of weight, and that, on the other hand, the oil asphalts may, and often do, gain in weight when kept at a high temperature for a prolonged period.

The type of viscosimeter used is believed to be practical and simple, but no hard-and-fast rule can be given in regard to the absolute time which a good binder must take in passing through a capillary tube of a certain diameter, equally good binders, as far as has been discovered, showing great variation in this respect, and in the specifications for each class of material quite wide limits of viscosity have been allowed.

Mr. Crosby appears to have made no statement in regard to specific gravity, but it has been found that the best materials of the different classes should have a certain specific gravity, if they are to be of value. For instance, the specifications of the Massachusetts Highway Commission state that the asphalt oils must have a specific gravity of 0.97. Oils with a specific gravity much less than this are light oils, with very little binding power and very little bituminous residue. They may be of some value in treating old roads, perhaps, but they are probably of little value in construction. To illustrate the simplicity of the specifications of the Massachusetts Highway Commission, those for refined tar and asphalt oils are included here.

As stated previously, however, it is not to be supposed that the specifi- Mr. Clark.
cations cannot be improved, and that they will not be improved by the Commission eventually, but it is safe to say that any refined tar answering to this set of specifications will be included, as nearly as can be determined, in that class which gives the best results in road work.

Suggested Specifications for Refined Tar.

The tar shall be uniform in color, character, appearance, and viscosity, and shall have the following qualities:

1.—It shall contain not more than 0.5% of mineral matter or dirt.
2.—It shall have a specific gravity between 1.18 and 1.25.
3.—It shall not contain more than 14% by weight of free carbon.
4.—It shall contain no body which distils at a temperature lower than 225° cent.; not more than 10% by weight shall distil below 270° cent., and it shall contain at least 65% by weight of pitch or bituminous material remaining after all bodies up to 360° cent. have been distilled.
5.—When 20 grammes are heated in a flat-bottomed dish, 3 in. in diameter, for twenty-one hours, in an oven kept at a temperature of 100° cent., the loss shall be not more than 10% by weight.
6.—It shall be of such viscosity that 60 cu. cm., measured at room temperature (78° Fahr. or 26° cent.), shall, when at 100° cent., be not less than 85 sec. and not more than 240 sec. in passing through a viscosimeter orifice $\frac{5}{64}$ in. in diameter, when acting under a head of $4\frac{1}{4}$ in.
7.—When $12\frac{1}{2}\%$ by weight of the material is mixed with $87\frac{1}{2}\%$ by weight of sand, of such grade that all of it will pass through a sieve having 10 meshes to the linear inch, and that practically none of it will pass through one with 190 meshes to the linear inch, and briquettes, 3 in. square and $\frac{1}{2}$ in. thick, are made, such briquettes will harden to such an extent in seven days, at ordinary room temperature, that when they are laid flat and held by their edges by two parallel knife-edge bars, they shall not bend when a weight is suspended from a third knife-edge or parallel bar placed across their center, until this weight reaches 200 grammes, and they shall not break at less than 250 grammes, and the weight which causes bending shall not be greater than 80% of the weight which causes breaking.

Suggested Specifications for Asphalt Oils.

The oil submitted shall be of uniform color, appearance, general character, and viscosity. It shall contain no bodies not naturally present in an asphaltic oil, and shall fulfill the following requirements:

Mr. Clark.

1.—It shall not contain more than 0.5% of dirt or adventitious mineral matter.

2.—It shall have a specific gravity of at least 0.97.

3.—It shall not contain more than 1% of matter insoluble in carbon bisulphide, and shall not contain more than 10.0% of matter insoluble in petroleum ether.

4.—It shall contain no body which distils at a temperature lower than 250° cent., and shall not lose more than 55% by weight by distilling to 360° cent.

5.—It shall be of such viscosity that 60 cu. cm., measured at room temperature (78° Fahr. or 26° cent.), shall, when at 100° cent., be not less than 5 min. nor more than 10 min. in passing through a viscosimeter orifice $\frac{5}{64}$ in. in diameter, when acting under a head of $4\frac{1}{4}$ in.

6.—When 20 grammes are heated in a flat-bottomed dish, 3 in. in diameter, for twenty-one hours, in an oven kept at a temperature of 100° cent., it shall not lose more than 5% by weight.

7.—When $12\frac{1}{2}$% by weight of the material is mixed with $87\frac{1}{2}$% by weight of sand, and briquettes, 3 in. square and $\frac{1}{2}$ in. thick, are made, these briquettes shall keep their shape and show some bond.

Mr. Blanchard's remarks in regard to mixtures of tars or refined tars and asphalts are very interesting. The fact that he builds the beautiful roads, which everybody seems to testify to, with this mixture, is simply another illustration that theory and practice do not always agree. Theoretically, Mr. Blanchard's roads should not be so perfect with this mixture, as the two bodies, when mixed, do not combine, as can be seen easily by examination under a microscope, and if the proportion is not right, a spongy, crumbling mass results, and briquettes made of sand and this mixture have no cohesion whatever. The fact stated by Mr. Blanchard that the asphalt comes to the surface and forms a surface coating, simply shows that the two bodies are not combined, but simply mixed, and the asphalt separates itself from the tar. Judging from the statements made, it seems to be one of the ways, and, perhaps the best way, of getting a surface coating of asphalt.

Mr. Grunsky.

C. E. Grunsky, M. Am. Soc. C. E. (by letter).—Prior to 1900 practically no attempt had been made to prescribe the quality of bituminous materials to be used for paving purposes in San Francisco, Cal. The first bituminous rock pavements (rock asphalt) were laid about 1887. The specifications were silent as to the physical or chemical properties of the asphaltic material, the most that was prescribed being a minimum percentage of bituminous material. Fortunately, the materials which were then available were admirably adapted

for paving purposes; the sand impregnated with the asphalt was of good quality, well graded, and, as has been demonstrated under the test of actual use, the asphalt was of a quality in every way suitable for paving purposes. It is not surprising, therefore, that the paving contractors succeeded, by a judicious mixing at the quarries of materials of various degrees of hardness, in furnishing rock asphalt serviceable alike under the hot summer sun in the interior cities of California and under the cool breezes of the Bay City. Mr. Grunsky.

Notwithstanding several failures of asphaltic wearing surfaces at Sacramento, there was put down, in 1888, a pavement in the rear of the State Capitol, under the advice and supervision of the writer, which, after 20 years, is still in fine condition, and on which there have been no repairs. The traffic, however, is not heavy.

The generally satisfactory quality of the bituminous materials used in California in street and road work is well recognized. The following, condensed from reports which the writer made in 1903, referring to the bituminous rock pavements of San Francisco, bears upon this fact. Some of these pavements were already more than 15 years old. The aggregate length of streets paved with bituminous rock was then 107 miles, and this mileage included many down-town streets having heavy traffic. The experience, since the first of these pavements was put down in San Francisco, indicates that about $200 per mile per year, with an additional allowance for re-surfacing annually an area equal to one-tenth of the roadway, the wearing surface of which is more than 10 years old, would keep the streets in good repair. This was not the amount actually expended for repairs. Many streets were in a neglected condition. The actual appropriation for repairs had fallen about $80 000 behind the amount that should have been expended, and the current appropriations for the purpose were only about one-half of what was required to keep the streets in good condition.

At that time it was estimated that pavements of this material, when more than 10 years old, would need minor repairs at a cost of about $1\frac{1}{8}$ cents per sq. yd. per annum, and that, in addition thereto, the wearing-surface renewal cost would be about $3\frac{3}{8}$ cents.

Several years prior to the date to which the above remarks refer, the City of San Francisco, under the writer's supervision, had established a testing laboratory. Plans were made for a careful examination of the asphaltic materials offered for use, as well as of asphalts extracted from pavements which had been in service for some time. It was hoped that such an examination would enable the chemist to detect those properties of bituminous material which were essential in making it valuable as a binder in the wearing surface of a street or road. No information is at hand to show whether or not this work has been carried forward successfully.

The abundance of bitumens and of oils with an asphalt base in

Mr. Grunsky. California, which are admittedly serviceable in road-building, has rendered the use of coal-tar products out of the question in that State. Not even the by-products of oil distillation were willingly accepted for use on city streets. On this subject, in 1902, as City Engineer of San Francisco, the writer called attention, as he had done in previous official reports, to the desirability of permitting the general use of oil asphalt in paving work. The view was taken that California is a great producer of oil, and, therefore, as far as practicable, the home uses of the products of the oil industry should be demonstrated and extended. The serviceability of oil asphalt as a substitute for the natural solid asphalt was not determinable short of a practical test.

"Its use on a few of the city streets, under various conditions of traffic and on different kinds of foundation will, it is hoped, go far toward determining the question of serviceability. It may be stated in this connection that the California oils nearly all have an asphalt and not a paraffin base, and that, therefore, the possibility of producing an asphalt, in the course of the oil-refining process, that will have properties practically identical with the natural solid asphalts, must be recognized."

It was pointed out that the market was stocked with the products of many refineries, that the origin of the products was not always traceable, and that even when the refinery was known, the source of the oils and the character of their mixtures might remain in doubt. It was also stated that at least five years should elapse before final judgment can be passed on an asphaltic paving material, and that, in some instances, even 10 years might be required to reach a verdict.

In the meantime the use of oils, and particularly of the heavy oils of the California type, as a binder in sampittic wearing surfaces has been rapidly extended, and the serviceability of California oils for such use has been demonstrated.

It is not to be hoped that there can be devised any laboratory process which will reveal fully the value of any untried bituminous material as a binder. This value will depend not only on a satisfactory condition of the road surface at the time of its completion, but also on its behavior under traffic, and this, in turn, will depend, among other things, on the nature of the rock particles which are cemented together, and mainly on the life of the bituminous binder. This useful life cannot be predicted for untried material until possibly after a sufficient number of successes and failures in actual practice have been recorded, together with adequate information relating to the properties of the asphaltic materials disclosed in the laboratory, and of all conditions under which such materials entered into the work. It may then be possible to write specifications so that they will exclude all undesirable materials while admitting all those which are known to be good. It appears to be hopeless at this time to devise laboratory experiments

or tests of the quality of substances of this class which, with the information thus gained, apart from actual use, will determine their paving value. The admission of untried materials, therefore, will always be with more or less risk of failure. Moreover, it follows from this that laboratory tests prescribed by specifications should be simple and require but little time, and that no attempt need be made to imitate in the laboratory the conditions under which the materials are to come into use. The old method of determining the petrolene and asphaltene contents of the bituminous compound, and then determining the viscosity, ductility, adhesiveness, hardness, and behavior in water, and under temperature changes, of a distillation residuum is just as likely to lead to a form of reliable specifications for materials of this class as a more complicated examination. Mr. Grunsky.

While the materials which are offered are being tried out on roadways, however, full records of their chemical and physical properties should be preserved, and the methods of ascertaining these properties should be standardized, so that from year to year the results may be compared. This is a matter which should not be confounded with the prescribing of simple yet adequate laboratory tests to appear or to be referred to in specifications for road work. The thorough discussion of this paper will be welcomed by all highway engineers, and it is to be hoped that the author's efforts to secure a standardization of laboratory processes and of specifications will bring about the desired result.

California is in the movement for good roads. The State is soon to vote on a proposition to issue bonds to the amount of $18 000 000 for new roads. One county is now expending $3 000 000 on its roads, and, in another county, a bond issue of $1 800 000 has been voted within the last few months for a similar purpose.

Henry B. Drowne, Assoc. M. Am. Soc. C. E. (by letter).—It seems to the writer that at the present time no very rigid set of specifications as to the essential qualities of some of the bituminous materials now on the market can be written. Chemical and physical tests will show that a bituminous material possesses certain characteristics, but whether or not these characteristics are detrimental or beneficial can only be ascertained by observation of the action of the material in the road for a period of some years. It is important now, however, to develop tests by which the materials can be analyzed, and to have enough tests, and of such a character as to account for all phases of the action of the material, from the standpoint of both construction and service. In order that work in different parts of the country can be compared, it is of the utmost importance that uniform methods of testing bituminous materials should be adopted, and the writer believes that Mr. Crosby's paper and its discussion will aid in bringing about this result. Mr. Drowne.

In the Rhode Island laboratory, the engineers have been trying

Mr. Drowne. to develop two physical tests of bituminous materials to show the cohesiveness of the different materials under uniform tension and sudden shock. For convenience, the test with the steady pull is called the cohesion test, and that with a sudden shock, the impact test. A series of experiments was made on 1-in. cubes of stone cemented together with different bituminous products. The methods used in making the tests were rather crude, but the results showed that with

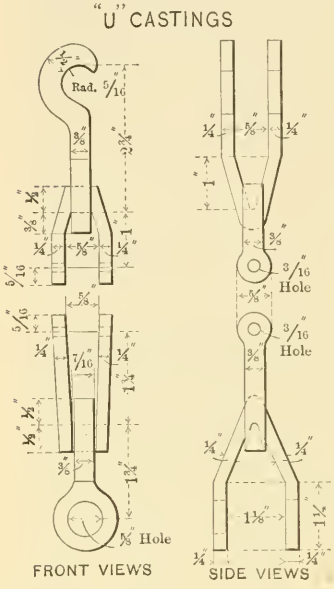


FIG. 1.

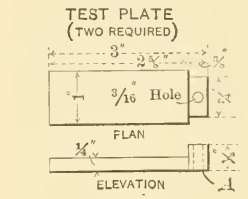


FIG. 2.

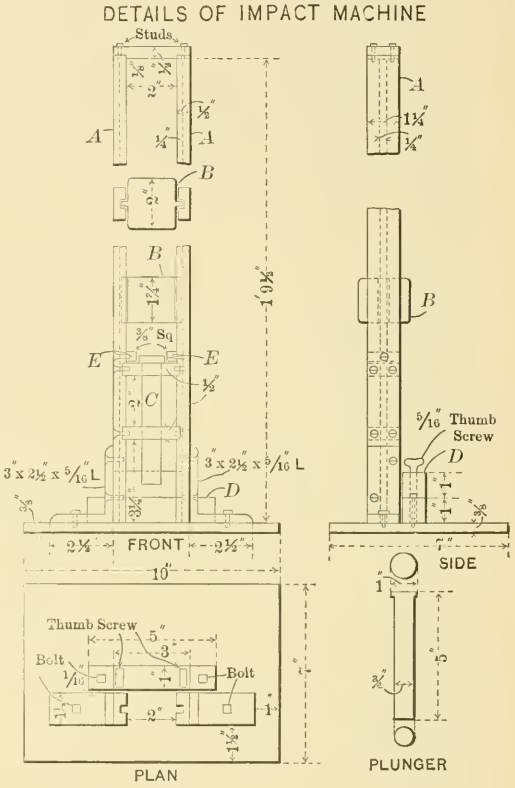


FIG. 3.

different appliances a satisfactory test might be expected. After some study, it was decided to use metal blocks for the impact test and metal plates for the cohesion test. Metal was chosen because the same surfaces could more easily be produced, the metal is easily cleaned, and is durable; whereas, with stone, the kind of stone, its structure, and porosity would all be factors which might affect the results of the tests.

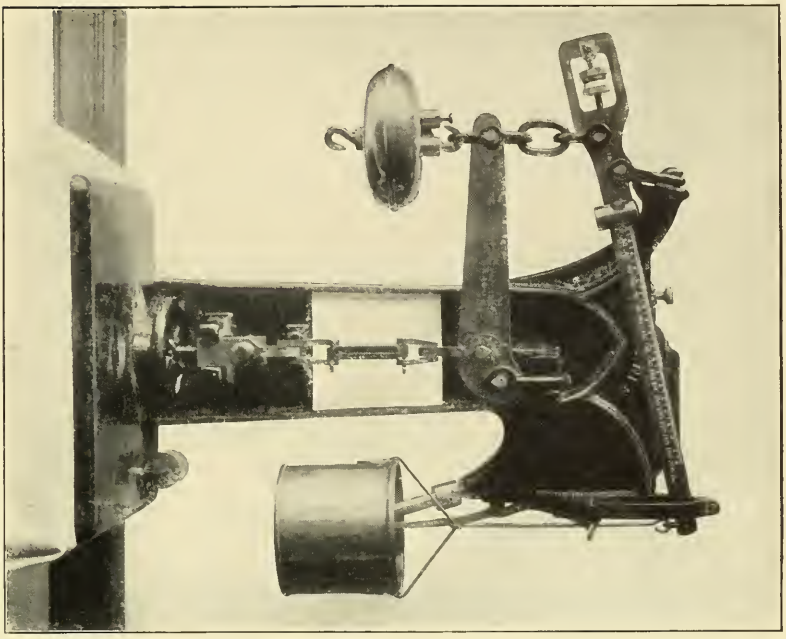


FIG. 1.—CEMENT TESTING MACHINE, MODIFIED FOR MAKING COHESION TESTS.

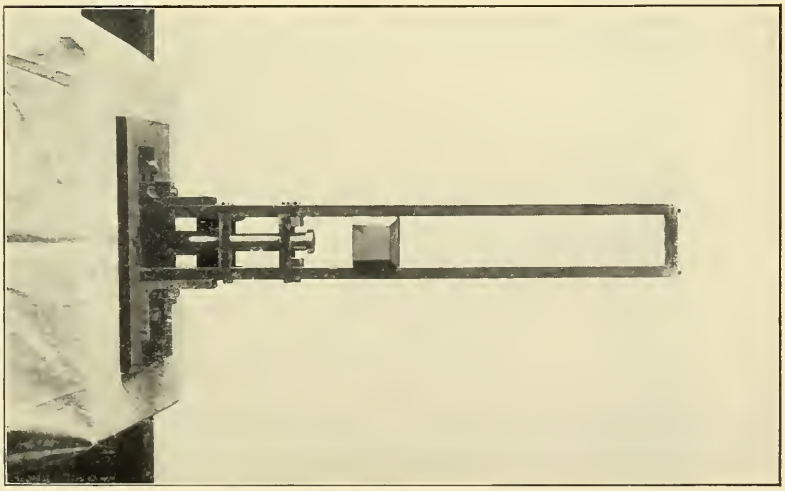


FIG. 2.—IMPACT MACHINE.

A Fairbanks cement testing machine, No. 3194, is used to provide the uniform tension required in making the cohesion test. This machine was selected because many of the State highway and other laboratories are equipped with one. The modifications necessary to adapt this machine to the cohesion test are simple and readily duplicated, as is shown by Fig. 1, Plate VII. The two clamps which hold the cement briquettes are removed, together with the cast-iron "U's" by which they are attached to the knife-edges and pin. These fittings are replaced by bronze castings of a different and lighter pattern, Fig. 1. As these castings are lighter than the ones removed, sufficient weight must be added to the large ball to bring the scale beam to a true balance. The test plates are bronze castings of such a size that a surface of 2½ sq. in. can be obtained. A shoulder is provided on the plates, so that when they are hung in the testing machine there will be no eccentricity of pull. The plates are cemented together, and are then connected to the upper and lower castings and tested. Mr. Browne.

The impact machine is practically a miniature pile-driver, as shown by Fig. 2, Plate VII. The essential parts are the leads, the 2-lb. weight, the plunger and guides, the clamp to hold the test blocks, and the stops on the leads to catch the weight when the specimen fails, Fig. 3. The test blocks are 1-in. bronze cubes. The blocks are cemented together and placed in the clamp so that one of the blocks comes under the plunger. The weight is then raised and allowed to drop on the plunger; the number of blows are noted, and also the height of fall of the weight that causes failure.

Francis P. Smith, Esq.—Mr. Crosby's paper is undoubtedly of great interest to all who are connected either directly or indirectly with the problem of modern road building. Under modern conditions, the natural cementing power of materials hitherto satisfactorily used in the making of roads is not sufficient to resist the abrasion and disintegration due to traffic. It is natural and logical, therefore, that improvement should be attempted by devising new means and methods to cement the particles of the roadbed more firmly together. Mr. Smith.

Sheet-asphalt pavements have taught us much as to the value of bituminous cementing materials for this purpose, their limitations, and the proper method of applying them. The data thus far accumulated respecting the treatment of roadbeds with various bituminous cements are, as Mr. Crosby states, woefully incomplete, and, consequently, much practical information which might have been drawn from the various experiments has been lost.

Past experience, however, has demonstrated conclusively that the success of a bituminous road surface depends on:

1.—The character of the foundation,

2.—The character of the mineral aggregate,

Mr. Smith.

3.—The cementing material used,

4.—The thoroughness of the mixing.

It is also true that the heavier the traffic the more carefully must each of these points be considered.

While it is specified that the treatment proposed is to be applied only to natural sandy roadbeds, in which the sub-drainage will presumably be good, it would seem that this point deserves more specific mention and provision than has been given to it. The problem of draining an ordinary roadbed is well understood, but this is quite a different matter. The road surface is to be water-proof, which means that no water can penetrate it from the surface downward, or from the foundation upward. Any moisture in the foundation can only be drained away; none of it can evaporate through the surface. It is not sufficient to provide drainage which would barely suffice for an average water level below the lowest point of the road. With an impervious surface covering the entire road, no water will drain from the foundation into the gutters, and when the frost comes out of the ground in the spring, the action of the sun's rays, combined with capillary action, will draw the water up from the foundation to the lower surface of the treated roadbed, where it will remain for a long time. The result will be that the bituminous road surface will be lying on a foundation of mud, and any heavy vehicle passing over it will rupture and displace it. This is not a theoretical consideration, as the experience of the speaker has amply proved in a number of cases where he made a personal examination of roads of this character.

If the mixing has been more or less imperfectly done and the traffic is heavy, the ultimate results may be the formation of an emulsified mud in which sand, bituminous binder, and water form an almost impassable layer from 4 to 6 in. deep on the surface of the road, and in one case this condition became so hopeless that it was solved (?) by the use of a scraper which removed the treated surface of the road completely. Instances such as these are quoted to show the vital importance of thorough sub-drainage and to demonstrate that, with a road of this class, methods of sub-drainage, formerly considered adequate, may prove to be totally inadequate.

Bituminous road surfaces, suitable for traffic, become quite soft in warm weather, and have but little inherent stability. It is necessary, therefore, that they be laid only on a firm foundation, as they will not bridge over any depressions in the sub-grade, but will substantially conform to and eventually reproduce the irregularities of the surface on which they are laid.

In certain respects, the problem of treating a roadbed in the manner suggested by Mr. Crosby is more complicated than the construction of an asphalt pavement. To a large extent, at least, the material to be cemented together is that found in the roadbed, and, while a certain

Mr. Smith.

amount of selection is provided for, the question of cost largely influences this. It has been found necessary in sheet-asphalt pavements to grade the size of the different particles of sand so as to produce the maximum amount of inherent stability in the mineral aggregate and thereby permit the use of a soft bituminous cement. In the manufacture of pavement of that type, the sand is heated and mixed, by suitable machinery, with the hot bituminous cement at a temperature of approximately 300° Fahr. Under these circumstances, a much harder bituminous cement can be used than when the mixing is to be done *in situ,* as Mr. Crosby describes, by using harrows, tamping rollers, etc. It would appear, therefore, that the question of grading the particles composing the mineral aggregate is even more important in road work of this character than in the case of an asphalt pavement, where, as has been seen, great attention is paid to this particular point. The lighter the traffic, the less important this problem becomes, but it should be borne in mind that the softer the bituminous cement, the more mushy the mixture; and the process of mixing described by Mr. Crosby necessitates the use of a soft bituminous cement. Properly graded sand particles will do much to offset this, and greater stability can also be obtained by the introduction of a certain proportion of crushed stone of suitable character.

Under the conditions described, the bituminous cement to be used must not only be capable of cementing the particles of the road firmly together, but it must be of such a character as to permit of its being readily incorporated with them. The requirements of the specifications, therefore, must insure the use of such a material. In the present state of the art, they must, to a certain extent also, be experimental in character, for the knowledge acquired through the use of bituminous cements in sheet-asphalt pavements is by no means sufficient in this case. Materials which would not be suitable for sheet-asphalt pavements may, under certain conditions, be used for road surfaces of this class. Experience has also demonstrated that certain bituminous cements may be used with certain kinds of soil, sand, or rock, which cannot be used under similar conditions with roadbeds of a different character.

All these considerations add difficulty to the task of preparing suitable specifications. Generally speaking, however, it is necessary to provide for:

(*a*).—Proper consistency,

(*b*).—Adequate cementing value,

(*c*).—Ease of mixing,

(*d*).—Retention of their cementing properties and consistency when incorporated with the roadbed.

These considerations apply equally to coal-tar products and asphaltic or semi-asphaltic binding materials.

Mr. Smith. Under the head of pitch compounds, Mr. Crosby's first test calls for a determination of the free carbon. This, undoubtedly, is an important point to be determined, as it has a close bearing upon (*d*). Coal-tars which are deficient in free carbon harden rapidly upon exposure, and soon lose their cementing value. On the other hand, an excess of free carbon renders them difficult to mix properly with the roadbed. It would seem logical, therefore, to prescribe both maximum and minimum limits. It is, perhaps, questionable whether the method suggested is the best which can be devised. Cold carbon disulphide is not the best solvent to use; it is difficult to extract all the soluble material from many coal-tar compounds by its use, and the method is tedious. A preliminary digestion with hot toluol and a final extraction in a Soxhlet type of extractor with hot benzol would be a better method, the speaker believes.

The fixed-carbon determination is wholly empirical, and is borrowed from methods in use in examining fuels. The method suggested by Mr. Crosby is different from that which has been standardized for use in the examination of fuels, and the results are to be "corrected for the amount of free carbon." Apparently, this is based on the assumption that none of the free carbon will be affected by the method of ignition prescribed. This test would appear to be of doubtful value, and the departure from the standard method referred to would make the results obtained useless for comparative purposes with those already tabulated.

The loss-on-heating test is, within limits, an indication of the stability of the bituminous cement, and, coupled with a determination of the penetration of the residue left after such heating, is a fair measure of the extent to which the material will harden when exposed on the road. In the case of coal-tar compounds, however, the contents of the dish should be stirred, from time to time, to prevent the formation of a skin of free carbon on the surface, thus preventing the evaporation of some of the lighter oils. While the formation of this skin in practice is an important function of the free carbon, unless it is broken up during the test it is very difficult to secure concordant results. It is difficult to see why, in the case of pitch compounds, the dimensions of the dish should be different from those generally used in the examination of bituminous products, as this prevents the results from being comparative. A 5-hour test is more suitable for many laboratories than one of 7 hours, and, for that reason, it is largely used in the examination of asphalts. Assuming that the free carbon is a necessary and valuable constituent of the compound, there would appear to be no reason for calculating the loss on heating on the weight of the original substance less the free carbon it contains, and such a practice would tend to render the comparison of different compounds very difficult and unsatisfactory.

Mr. Smith.

The method of determining the melting point of the residue is different from that used by very large manufacturers of pitch compounds, and, again, the results would not be comparative with those already established.

The method of distillation described under Clause *d* is not very clear. Is it assumed that the distillation must be carried to a point above 225° cent. to effect the same loss as is found on heating, as described under Clause *c*? The value of the fractional distillation, proposed as a measure of the suitability of the compound for the purpose, is questionable, perhaps, but, as an experimental investigation, it may eventually prove to be of value.

Tests intended to measure the consistency of the material and the degree to which it will lend itself to ready incorporation with the roadbed are undoubtedly of value. The viscosity test proposed may eventually lead to something satisfactory, and the taking of viscosities at different temperatures is to be recommended. The attempt to use a penetration machine with a No. 2 needle under a load of 100 grammes at 100° cent. and 35° cent., will doubtless be abandoned, as the consistency of a suitable bituminous cement for this purpose will be softer than can be determined by such a method with the machines at present in use.

To review these tests briefly, it would seem to be a mistake to depart from such methods as have been already standardized by extensive use, unless much is to be gained by so doing, and the modifications suggested seem to present no marked improvement over the older methods.

While an attempt has been made to provide tests for regulating consistency, ease of mixing, and ultimate retention of cementing properties, no steps have been taken to measure the cementing value of the bituminous cements used.

The speaker would suggest the moulding of test briquettes, made of standard sand, or of the roadbed to be treated, combined with the proper proportion of bituminous cement. These briquettes should be moulded by machinery under fixed pressure and then pulled apart in specially constructed clips, at a definite temperature or temperatures. The tensile strength of such briquettes would give, at least, a comparative idea of the cementing value of the bituminous cement, and by using it with material actually taken from the roadbed to be treated, much valuable information, as to the ease of incorporating it, could be obtained. If necessary, the bituminous cement should be evaporated down at a low temperature until it acquires a specified consistency, thus increasing its cementitiousness more nearly to the point which it would reach in the course of time after it had been incorporated with the roadbed.

In the case of petroleum or asphaltic pitches, the tests prescribed

Mr. Smith. are naturally, and very properly, somewhat different from those to be applied to coal-tar pitches.

The method prescribed for the determination of the fixed carbon is the same as that for coal-tar pitches, and the remarks under that head, as to the methods used, apply equally here. The determination of the free carbon in asphaltic materials of this class is of very doubtful value. Certain oils, utterly unsuited for road-making purposes, which the speaker has examined, have a higher percentage of fixed carbon than others of undoubted value, and the reverse is also true. For certain commercial reasons, the percentage of fixed carbon has been exploited as a measure of the commercial value of paving asphalts, but the claims put forward have never been substantiated.

The determination of the free carbon, as measured by the comparative solubility of bitumens in cold carbon disulphide and cold carbon tetrachloride, is another test of the same character. Certain asphaltic compounds are more soluble in carbon tetrachloride than in carbon disulphide; and with others the reverse is true. Certain other bituminous materials, containing more than 50% of bitumen soluble in carbon disulphide and insoluble in carbon tetrachloride, have been used successfully as paving materials. It would seem absurd, therefore, to limit the permissible difference in solubility, in respect to these two solvents, to 3 per cent. The more important question is whether this so-called free carbon is soluble in the compound itself, and the results obtained, in the use of coal-tars as cementing materials in this class of work, has proved that from 15 to 20%, and even more, of free, inert carbon is not necessarily a detriment to the cementing value of the material.

Excessive quantities of paraffin may be objectionable, but if the paraffin is in complete solution it may, on the other hand, be little or no detriment. The test described is a difficult one to make, and the results obtained are not very satisfactory.

The loss-on-heating test should be conducted preferably for 5 hours at 325° Fahr., for the reasons previously mentioned. This is the generally accepted time and temperature at which this test is made.

The test for solubility in 88° naphtha is similar to that used in the examination of asphalts. Just what value it possesses has never been clearly demonstrated, but it is probable that most suitable materials will comply with the requirements set forth. Certain products, however, are suitable for use on roadbeds largely composed of limestone which, when treated with naphtha, will not give a solution which leaves a sticky film on evaporation.

The question of determining the proper consistency by viscosity tests is a difficult one. A viscosity which will be suitable as a requirement for certain oils will not answer with others. The limits set for

this particular test, therefore, will probably have to be so wide as to impair greatly its value as a specification requirement. Mr. Smith.

The penetration test, as described, will not be applicable, for the reasons stated when discussing the specifications for pitch compounds.

With many compounds, an evaporation test for 21 hours at 225° cent., will not give a residue sufficiently hard to render it possible to take a penetration test of it at 25° cent. It would appear to be preferable to specify a given temperature, not above 260° cent., and a given consistency to which the material must be evaporated, leaving out of consideration the time required, and to specify the maximum limit of the residue to be thus obtained. While it is true that the character of this residue is not identical with that formed in the road by slow evaporation, nevertheless, in a number of instances where the speaker has examined the bituminous cement used in the construction of a road and that subsequently extracted from the treated roadbed, or the residue left in it after the lapse of a considerable period of time, the two residues have shown marked similarity.

The determination of the penetration of the residue left on evaporation at the two different temperatures noted in the specifications will give valuable information as to the susceptibility of the cementing material to changes in temperature. It might also be advisable to determine the penetration at a third, and higher, temperature, approximating 38° cent. If this is done, the residue should be evaporated down in the original test until it has obtained a penetration of 50 at 25° cent.

Compounds prepared from petroleum are, perhaps, more difficult to examine than those prepared from coal-tar, as crude petroleums differ much more than crude coal-tars. The test for determining the cementing value of the coal-tar pitches would apply also to petroleum compounds. In the method described by Professor Blanchard for determining the cementing value of the compound, he applies the bituminous material to a metallic surface and measures its cementing value as applied to that surface. This, unfortunately, is not a true measure of its cementing value when applied to sand or different kinds of rock, for, as previously noted, certain bituminous compounds which adhere well to certain kinds of rock are totally unsuited for use with others.

The question of the proper mixing of the bituminous cement with the roadbed is a very important one, and on it much of the ultimate success of the process depends. Most of the methods used for distributing the bituminous compound on the surface of the road are very faulty, and leave a number of pools of it on the surface, thus increasing the difficulty of incorporating it thoroughly into the roadbed. If the oil were thoroughly atomized and applied to the road in the shape of a spray, much of this difficulty would be avoided. There are a number of mechanical devices suitable for this. An ordinary oil burner may be attached to the cart containing the bituminous com-

Mr. Smith. pound, and the oil may be sprayed through this by a current of compressed air. If the sprinkling cart and a harrow were coupled in tandem and the spray of oil were directed upon the earth just as it was turned up by the teeth of the harrow, almost 50% of the mixing operation would be completed simultaneously with the first application of the oil. Experiments along these lines are now being conducted by the speaker, and they give promise of very satisfactory results.

Mr. Howard. J. W. HOWARD, ESQ.—It is now too late to comment on the tests of bituminous or asphalt road cements submitted by the author, because those tests have been completely eliminated or changed by Mr. Crosby and others. Physical and chemical tests are needed, which will be in more direct relation to the practical necessity of determining the essential qualities. A large number of experiments with many kinds of bituminous substances have been completed, and there is sufficient information as to the qualities of such cements and road oils to repeat a bituminized macadam or other road, so that previous successful results will be assured. There is also sufficient information to determine, within a reasonable degree of accuracy, whether or not a new or untried asphalt road cement can be made to succeed when used to indurate the surface stratum of a road. For economic and efficient results, it is best that the road material, to a depth of an inch or more, according to location, weather, and traffic, be mixed or incorporated with the cementing substance and not rely on the pouring of oils and cementing substances on the surface of finished roads. This last method gives only temporary relief from dust, and adds comparatively little to the durability of a road, although, in many cases, it is wise.

When called on by contractors, municipal, or state officials, as a consulting engineer on roads and pavements, the speaker finds it necessary to give, not theory, but positive and definite instructions as to what to do, although scientific knowledge and theory are essential safeguards. The problem must be solved more from the standpoint of civil engineering than chemistry, although chemical and physical tests are necessary. These tests should be such that an educated civil engineer, with some chemical experience and a properly equipped road laboratory, can make them, determine the quality of the road cements or binders which have been used, and show wherein they are successful or the reverse, and also predetermine the successful use of new materials or those not yet tried in practice.

Among the necessary tests of road cements, the following are suggested:

1.—Purity of the bitumen, tested by solution in carbon disulphide, the bitumen being the cementing portion of bituminous or asphalt road cements.

2.—The residue remaining, and its nature.

3.—Petrolene, tested by solubility in standard 75° Baumé naphtha, this being the soft portion of the bitumen. Mr. Howard.

4.—Asphaltene, which is the remainder or hard portion of the bitumen of road cement.

5.—Specific gravity.

6.—Free carbon or inert coke.

7.—Water content.

8.—Solubility of the asphalt road cement in water, or how seriously it is affected by water.

9.—Flash point, to indicate stability or durability, and to avoid danger in heating for use.

10.—Flow on a glass plate at an angle of 45° at 77° Fahr.

11.—Penetration of a No. 2 needle under 50 grammes weight during 5 sec., made on the material at 32° Fahr. (and not at 77° Fahr.), because road cements are generally too soft to be thus tested at 77° Fahr.

12.—Viscosity or flow of 50 cu. cm. of the material at 212° Fahr., measured by the number of seconds needed for this flow in a Howard hot-water, jacketed viscosimeter, or other equivalent apparatus.

13.—Ductility at 32° Fahr. of a briquette, the smallest cross-section being 1 sq. cm.

14.—Adhesiveness at 100°, 77°, and 32° Fahr., respectively, determined by the Howard tension briquette method, or other equivalent method.

15.—Brittleness at each of the three temperatures just mentioned.

16.—Volatilization or percentage of loss of weight at 220° Fahr., during 5 hours, applied to 25 grammes in a hot-air oven, not on a hot plate over a direct flame.

17.—Volatilization under the same conditions, except at 325° Fahr.

18.—Volatilization at 500° Fahr. in an air oven, of 50 grammes, until the residue, when cooled to 77° Fahr., has a penetration of 10 mm., tested with a No. 2 needle under a load of 100 grammes during 5 sec.

19.—The ratio or percentage of the last-mentioned residue to the normal material.

20.—Melting point, by the Howard mercury melt test apparatus, or equivalent method, of the last-mentioned residue.

21.—Ductility of a briquette of the same dimensions (1 sq. cm.) before mentioned and tested at 77° Fahr., also ductility at 32° and 100° Fahr., when possible.

22.—Temperature at which the normal material is of proper fluidity for use, and the limits between which it should be kept hot, without being injured, while being used.

There are several other tests and methods which are being developed, and these, in conjunction with some of those given above, seem destined to become standard, especially if not interfered with or influenced by

Mr. Howard.

the commercial motives of persons connected with any special brand or kind of road-cementing material.

The speaker strongly urges the adoption of 5 hours as the length of time for making volatilization or evaporating tests, because this gives not only practical results, but enables the observer to prepare his tests in the morning, watch them personally through the day, and finish them by night. It is foolish, unnecessary, and inexact to require 24-hour tests, or any such protracted heating tests, because they cannot be personally observed, and, in case of dispute, they become matters of opinion and not of fact, and do not yield such practical results as are obtained by 5-hour tests.

The speaker firmly objects to the determination of the percentage of residues remaining after heating by using direct flame under the material, thus subjecting and destroying portions of it at temperatures above those prescribed; he believes, however, that all heating should be done in hot-air ovens with a free circulation of air, so that no portion of the material, when being heated, is subjected to contact with any heat in excess of that prescribed; also that all heating should be done at definitely stated degrees of heat and, in no case, be (as has been advocated by a few) "evaporated at a heat not to exceed a given heat, say, 500° Fahr." When this last is done, variable results are obtained by various heats under 500° Fahr. or other maximum. These permit of no definite conclusions nor proper comparisons between bituminous or asphalt cements from different sources nor even from the same source. The residues should not be called the "asphalt portion," because they are not.

The foregoing is by way of suggestion. The subject is one involving the preservation of many thousands of miles of roads which cannot be maintained economically without being bituminized by one of many successful modern methods and other methods in process of development.

The speaker is of the opinion that many engineers and chemists fail to examine the recorded successful results in several parts of the United States and Europe, and, therefore, constantly experiment at large private and public expense, to the injury of many miles of roads and unnecessary waste of money. Private, proprietory, commercial, and so-called political interests or influences to favor one or another material will be avoided by Members of this Society and by all who are true to their profession.

Mr. Richardson.

CLIFFORD RICHARDSON, M. AM. SOC. C. E. (by letter).—After a careful consideration of Mr. Crosby's paper, as it was presented before the Society, the writer is in complete accord with the statements of Mr. L. W. Page, Director of the Office of Public Roads, U. S. Department of Agriculture, Washington, D. C., and with the criticisms of Mr. Prevost Hubbard of the same office. There seems to be nothing to add to what these gentlemen have said; their views appear to be very sound.

Mr. Crosby.

WALTER WILSON CROSBY, M. AM. SOC. C. E. (by letter).—In reviewing the discussion the writer wishes to emphasize the statement in the paper, that it was not his purpose to propose a standard specification for pitch compounds used in road-making, to be followed blindly no matter what variations in the conditions might be expected on the completed road, or in the method of using the pitch compounds, but to furnish a concrete starting point from which a standard form of specifications could be adopted; and, the standard form having been secured, the variations in conditions could be met by such changes of the figures in the form as expert judgment should dictate.

Messrs. Hubbard, Page, and Richardson seem to have misunderstood the writer's intention to some extent, and he infers that he has not made himself clear. He believes that they will concur with him in the idea of standardizing a form of specification for pitch compounds, for the reason that Mr. Page is Chairman and Mr. Richardson (if not also Mr. Hubbard) is a member of a Committee of the American Society for Testing Materials which has for its object "the standardizing of tests for bituminous materials," and this Committee, as Mr. Page has informed the writer, is expected to render a report by July 1st, 1909.

Messrs. Hubbard, Page, and Richardson certainly have misunderstood the writer if they believe it was his intention to provide strictly for all conditions by the specifications for pitch compound in Sampittic Surfacing. The writer specifically stated that the specifications for "Sampittic Surfacing" were used as a starting point for discussion, principally because it seemed that the simplest method in the use of a hydrocarbon cement would thus be considered; and, further, it seemed probable that, if the proper standardizing of the base were secured, the particular modifications of the base, as required under different conditions and for different purposes, might be met by the changes in the inserted figures such as the necessity might dictate.

Mr. Page says that "in many instances experiment alone will determine what binder is best suited to meet given conditions." This may or may not be true at the present time, but it is the hope of the writer that, in the near future, where the given conditions can be stated, it may be possible to prescribe the necessary binder more scientifically, more accurately, and more cheaply than by experiment.

Under date of September 22d, 1908, the Office of Public Roads, U. S. Department of Agriculture, of which Mr. Page is Director, issued a bulletin* on "Dust Preventives" by Prevost Hubbard, in which, on page 53, it is stated that:

"Considerable research is required before entirely satisfactory methods of examination and specifications can be decided upon, and it should be understood that the following are offered as a guide only."

* Bulletin No. 34.

Mr. Crosby. And, on page 57 of the bulletin, the suggested specifications for "a refined tar" are as follows:

"(*a*) The coal tar should be one formed at a comparatively low temperature, such as that produced from by-product coke ovens or by gas plants which use no enriching materials for increasing the illuminating value of their gas.

"(*b*) The specific gravity should not be lower than 1.17 nor higher than 1.20.

"(*c*) No water nor ammoniacal liquor should be present, and the boiling point should be above 110° C. (230° F.).

"(*d*) Upon distillation at least 40 per cent. by volume of pitch should remain after all oils have been driven off below 270° C. (518° F.)."

On page 61 of this bulletin the suggested specifications for asphaltic oils are as follows:

"1. The oil shall have a specific gravity of not less than 0.95.

"2. Its flash point shall be not lower than 300° F.

"3. It shall be free from water as determined by the gasoline test.

"4. When heated to 400° F. * * * for seven hours its loss in weight should not be over 35 per cent. The character of the residue should be smooth and nearly solid when cold, but not so hard that it may not be easily dented with the finger, and when soft it should pull to a long, thin thread.

"5. The oil shall be soluble in carbon disulphide to the extent of 98 per cent., and in 88° naphtha to at least 88 per cent."

Mr. Page and Mr. Hubbard think that general specifications for pitch compounds, and rather satisfactory ones in some instances, can be framed to advantage. The writer's form appears to him to offer much more elasticity to individual cases, and to cover more ground in many of its terms.

Mr. Page objects to the time required for the tests proposed, but attention is called to the fact that the time occupied by the standard test for lime cement is much greater than that required for the proposed test of pitch compound, in spite of the fact that the lime cement is a much simpler material. The writer agrees with Mr. Page that it is extremely desirable that an examination be generally made of all the bituminous binder materials and similar materials now being used, but he submits that, unless a standard form of examination is adopted, the results of such examinations will be of little value for comparison, and the situation will not be changed materially from what it is at present.

In presenting this paper, the writer stated that information secured since the initial offer of the paper had led him to abandon many of his earlier conclusions regarding the clauses of the specifications for pitch compound, and to change materially many of his views in reference to them; and that, at the later date, he had been convinced that

separate specifications, as since suggested by Mr. Hubbard in his discussions of tars and asphalts, were necessary. Mr. Crosby.

The discussion of the sections of the specifications will be taken up seriatim:

Mr. Page says:

"Strict limitations with respect to certain constituents, such as free carbon, fixed carbon, paraffin contents, etc., are, at the present time, based on matters of personal opinion rather than on established facts."

Mr. Hubbard, supported by Mr. Richardson, states that "any specification limiting the percentage of free carbon to 10 is applicable to tars only." The insertion of the clause limiting the percentage of "free carbon" in tars was induced by Mr. Hubbard's statements in the bulletin quoted. Subsequent investigations, however, have convinced the writer of the uncertainties of the value of such a clause, and of the desirability of further information regarding the results of the presence of "free carbon," except possibly in the case of asphalts.

The latest information does not indicate that the limit in the case of tars should be placed below 35 in many cases, and possibly even higher, while in many other cases it would seem necessary to require the presence of "free carbon" above a minimum figure in order to secure the proper materials. It is possible that the specifications concerning the "free carbon" will finally determine its presence in terms of percentage of some other constituent. At present the best tar of which the writer has practical knowledge is a refined high-temperature water-gas tar, with less than 1% of "free carbon." The next best is a refined low-temperature tar which, in its semi-solid or "soft pitch" state, contains 35% of "free carbon."

Mr. Smith assumes that free carbon is a necessary and desirable constituent of the compound, and therefore objects to the calculation of loss on evaporation on a basis of compound free from free carbon. This assumption may or may not be justified, and further information is probably necessary in order to decide its fairness. Therefore, during the collection of this information, it would not seem to be unfair to base the calculation of loss under evaporation on that portion of the compound other than the free carbon. As stated above, the writer's experience does not lead him to believe that free carbon in all cases adds to the value of the compound.

As regards Mr. Smith's suggestions for the determination of "free carbon," the writer believes that, at least until some information is at hand regarding the value of any determination of this constituent, the cold carbon disulphide method will answer for the purpose, and will be much more convenient and less expensive for a new laboratory.

As to the "fixed carbon," the writer believes that the value of such a clause also depends on further information concerning it.

The standard Mr. Smith refers to is the standard for the determina-

Mr. Crosby. tions of fixed carbon in coals and similar substances, and this method is difficult, if not impossible, to use on pitch compounds for road-making purposes, and, therefore, has been modified to meet the requirements of the softer materials.

Mr. Smith, in his discussion of the specifications for asphalt pitches, says: "The determination of the free carbon in asphaltic materials of this class is of a very doubtful value." The writer cannot agree with him on this point at present, and it would seem that it can quite safely be stated, as Mr. Hubbard says, "the amount of material insoluble in carbon bisulphide could be limited to 2% for most asphaltic products," and should be reduced to this figure at least if the asphalt material is to be guaranteed. The writer thinks he is erring on the safe side, at least, by requiring that there shall be not more than 3% of variation in the solubility of the material in carbon bisulphide and carbon tetrachloride.

The writer also believes that the test for paraffin errs on the side of safety, if in error at all.

In view of the uncertainties regarding "fixed" and "free carbon" specifications, and while it may be desirable to omit these clauses from the specifications for road compounds, it is extremely desirable to secure further general information on these points.

As regards Mr. Smith's criticism of the loss-on-heating test, the writer, in order to avoid the necessity of the mechanical stirrer, which would be difficult to arrange in some highway engineers' laboratories, proposed to use a dish of a size which would cause the exposure of the material in a relatively thin film, with the temperature lower than that commonly used in a similar test on asphalts.

Mr. Smith says that the limit set for the viscosity test will probably have to be so wide as to impair greatly its value as a specification requirement. In view of the importance of controlling the consistency, and with an idea of reducing this width to a practical application, the writer, in his modified specifications, quotes several different instruments, so that all varieties of compounds may be compared closely.

Mr. Smith suggests that in the second evaporation test a given temperature be specified and a given consistency be named to which the material shall be evaporated, and that a minimum limit of the residue thus obtained should be stated. This would be a most difficult test to carry out, as it is almost impossible to evaporate to a definite consistency, and, unless the consistency is definite, the results of the test would be worthless.

As Mr. Smith says, in determining the cementing value of pitch compounds, it may ultimately be deemed advisable to consider the kind of material to which the cement is applied, and, of course, it is possible that stone surfaces will be substituted for the metallic surfaces used by Mr. Blanchard and Mr. Browne.

Mr. Smith objects to the melting-point test proposed. In view of the fact that scarcely any manufacturers or chemists agree on a melting-point test, it will be well enough at present to continue with the simple one proposed. Mr. Crosby.

The writer agrees with Mr. Smith that the use of a penetration machine with a No. 2 needle loaded with 100 grammes at 100° cent. is impracticable in some cases. In the revised form of specifications it will be found that provision is made for specifying the viscosity or consistency of the cement according to the measurement of one or more of four or five machines.

With regard to Mr. Smith's objection to departures from such methods as have already been standardized, the writer agrees with him that such departures are to be avoided unless absolutely necessary; but Mr. Smith will agree that, owing to the different nature of the pitch compound from the materials for which the standards were created, material departures from the standards may be necessary in many cases, and while, of course, it is clearly advisable to adhere to established standards as closely as possible, it would be most unfortunate conservatism which would refuse to depart from the "standards" when such departures were made necessary by the inapplicability of standards for use on one material to material of quite a different nature, especially if such refusal were based simply on the ground that a departure was being made.

As regards Mr. Smith's suggestion for moulding test briquettes, the writer later expresses his opinion in his remarks on Mr. Clark's specifications.

The test of solubility in 88° naphtha seems to be a valuable one, and it is believed that while certain compounds which would not pass this test might possibly give satisfactory results under certain conditions, the test in a general way is of the greatest value in cutting out uncertain or unfit material.

The writer desires to express his sincere appreciation for the suggestions of Messrs. Blanchard and Drowne, and by agreement he is at present at work on some adhesion tests similar to those they have suggested.

Mr. Sharples suggests that too many tests are required, and that many of them are too complicated. In the revised specifications the tests for tars are limited to eight, and those for asphalts to ten. The Massachusetts specifications, which Mr. Sharples points to as models, require seven each for tars and asphalts. The writer agrees with Mr. Sharples that it would be desirable to reduce the number as much as possible, but he thinks that, in view of the limited knowledge of the subject at present, it is incumbent on him as an engineer to protect his clients by insisting on an extra test or two and by refusing to take

Mr. Crosby. any chances for the sake of other parties by omitting any test likely to be of value.

Mr. Sharples suggests that the tests should be as simple as possible and "easily executed in any works laboratory without special apparatus." As an academic ideal, the writer agrees with him, but the avoidance of the special apparatus for the testing of these complex materials seems to be at present impossible. Mr. Sharples himself suggests both the distillation and viscosity or penetrometer tests, so that evidently he did not mean to omit the "special apparatus" entirely.

The recommendations of Mr. Clark are especially interesting, and the writer hopes that, as Mr. Clark says, his specifications will "surely" cause the use of desirable binders. It is true that some are more simple than those suggested by the writer, except possibly his No. 7, and it is to be hoped that they are not so simple as to be too open, and thus permit the use of inferior materials.

As regards Mr. Clark's tests, it seems to the writer (from information available to him from considerably more than 1 000 determinations of these materials by his chemists) that the specific gravity may or may not mean anything in particular. It seems entirely possible to secure absolutely different materials of the same specific gravity, and it is true also that similar materials will have great varying specific gravity. It is possible that this clause, taken into consideration with other clauses, may have some definite value, but at the present time it seems to be decidedly questionable whether or not it is worth while to insert the specific gravity clause in the specifications for pitch compound for road purposes.

As regards Mr. Clark's No. 3, the uncertainties of the writer regarding "free carbon" have been expressed above. In his Test No. 4, the percentage of distillates will be fixed, of course, by the methods to be followed in using the materials. In Test No. 5, it would seem that the temperature, 100° cent., is unfortunate, as is, also, the size of the receptacle. The receptacle should either be larger, in order to secure as thin a film of the material as possible, or it should be similar, and preferably of the same diameter as that in use for a number of years in testing asphalt, and the material in the receptacle should be stirred sufficiently to prevent the formation of a film on the surface.

It is not advisable to adopt a temperature of 100° cent. for the evaporation test because of the difference in the results caused by the change of one or two degrees from the standard temperature. The variation would be much smaller if 105° cent. was adopted as a mean, permitting a variation of one degree either way.

In his Test No. 6, it is unfortunate that Mr. Clark neglects to state the length of the viscosimeter orifice, a most important detail. It also appears to be most unfortunate that Mr. Clark abandons entirely the use of such readily available viscosimeters as are now on the market.

Mr. Crosby. As regards No. 7, the writer cannot agree with Mr. Clark at present. If it is desirable to introduce such a test, the writer would much prefer a test of the material itself, as suggested by Messrs. Blanchard and Drowne.

At present, nothing will be gained by introducing new uncertainties, such as exist in the foreign material, sand, with all its variabilities. The desired information can be secured more accurately by such tests as for the stickiness of the naphtha-soluble portions or the adhesion and cohesion tests referred to by Messrs. Blanchard and Drowne. As far as the writer is aware, no tar is sufficiently lacking in adhesive qualities as to warrant any test of this nature.

In reference to Mr. Clark's specifications for asphalt oils, the same remarks as above apply to No. 2.

No. 3 appears to conform to the generally established process in asphalt work, and to prescribe a maximum for the difference in the solubility in carbon bisulphide and carbon tetrachloride.

As regards No. 4, the writer sees no reason for distilling the asphalt compound, as he believes that standard evaporation tests for such substances are all that are necessary.

As regards No. 5, the same remarks apply as to No. 6 for refined tars.

As regards No. 6, the same remarks apply as to No. 5 for refined tars.

As regards No. 7, the writer's opinion is stated above.

In reference to the briquette test, Mr. Clark states: "chemical analyses are of more importance in many respects than any physical test," and "in studying these briquettes, * * * it is fairly evident that it does not necessarily follow that those binders which soonest produce hard and strong briquettes are the most valuable." The writer agrees with Mr. Clark that simple tests are desirable, but in this he fails to see the advantage which Mr. Clark's specifications obtain over those by the writer as last presented.

Laboratory tests, as Mr. Grunsky states, must be supplemented by the use of the materials. Engineers must endeavor to attain this end, for the unsatisfactory conditions to-day are largely due to the fact that these investigations have not been begun before and that they have not even yet been begun on common lines in laboratory investigations. No attempt to imitate in the laboratory the conditions of actual use may be necessary, but laboratory analyses may indicate the probable value of the material, if they do not prove it.

Mr. Howard states that there is already sufficient information, as to the qualities of cements and road oils, to repeat a bituminized macadam or other road, so that previous successful results will be assured, and there is also sufficient information to determine, within a reasonable degree of accuracy, whether or not a new or untried road

Mr. Crosby. cement can be made to succeed. The writer is forced to disagree with Mr. Howard in this statement. Doubtless, if accurate information on all the twenty-two points (mentioned by Mr. Howard as the many necessary tests of road cement) were available in any case of successful work, similar success could be hoped for in the new work, if, however, not too great a variation from the recorded figures is to be allowed. Just what variation should be allowed in any case would probably be a matter of much discussion.

Mr. Smith, of course, had before him only the specifications relating to the surfacing, and did not know that the points he makes regarding drainage were taken care of in other portions of the specifications for the road. The writer agrees with him regarding the necessity for proper drainage.

Better results could be secured for sampittic surfacing by dividing the surfacing into two classes, and, in the final form, it will be found that this has been done.

After further investigations, and after discussions received by the writer previous to the presentation of the paper, he reached the conclusion that it would be better to separate pitch compounds into two classes, (*a*) the tar products of coke ovens and gas-works, and (*b*) the petroleum residuums and fluxed asphalts; and then to provide separate, though perhaps similar, specifications for each class. This conclusion was stated by the writer in presenting the paper, and some of the later discussions point to the suggestions which he expressed verbally at that time. With the changes suggested above, and embodying all the suggestions in the discussion which the writer believes would improve them, the revised specifications are herewith submitted.

The writer desires to express his sincere appreciation to those who have taken part in this discussion, for valuable suggestions which have assisted him materially. He believes, further, that knowledge on this subject is far greater than it was even a year ago, but that more discussion is necessary, and that it is only by co-operative work on the part of those familiar with, or interested in the subject, and work free from personal or business prejudices, that definite conclusions can be finally reached regarding the necessary and unnecessary clauses in specifications for "Pitch Compound."

REVISED SPECIFICATIONS.

Sampittic Surfacing.

Sampittic surfacing shall be used wherever provided for in the plans or directed by the Engineer. The width and class or classes required at different points shall be those shown on the plans or designated by the Engineer. There may be two classes of sampittic surfacing, as follows:

Class A shall consist of one 6-in. course of a thorough mixture of pitch compound and sandy soil, to be formed on the roadbed after the latter has been properly graded and shaped.

Class B shall consist of one 6-in. course of a thorough mixture of pitch compound and sandy gravel, to be made off the road and then spread on the roadbed after the latter has been properly prepared, as hereinafter provided.

Roadbed.

Material.

The roadbed for the sampittic surfacing shall consist of the natural sandy roadbed, prepared and shaped as shown on the plans. Where the natural roadbed is found, during the work, to consist of material which, in the opinion of the Engineer, is unfit for this form of construction, the Contractor shall remove as much of this unfit material as may be deemed necessary by the Engineer and shall replace it with sandy material which, in the opinion of the Engineer, is suitable for the purpose. All unfit material thus removed will be measured and paid for as "Excavation."

Cuts and Fills.

In cuts, unless otherwise specially directed, the roadbed shall be graded to a wdith of 24 ft., and shall be free from spongy and vegetable matter, roots, and stumps. The portion of the roadbed prepared for the pitch surfacing shall be 18 ft. wide, and shall be brought to the grades and cross-sections shown on the plans. The fills shall be 26 ft. wide on top.

Old Earth Roadbed.

Where no change from the present grade of those portions of the road not already surfaced is shown on the profile, the roadbed shall be shaped to the proper cross-section; and slight elevations, with contiguous depressions, shall be removed, so as to form an even and smooth surface.

Shape.

The shape for the finished road shall be that shown on the accompanying plans, and shall have a cross-slope of ½ in. to 1 ft.

Pitch Compounds.

The pitch compound to be used shall be a hydrocarbon, refined from tar or petroleum, or made from natural asphaltic pitches by the use of a proper solvent or flux. If made from tar, it shall be uniform in character, free from water and water-soluble materials, or dirt, or other adventitious material, and shall possess the following characteristics:

A.—The percentage of free carbon shall be not more than 30.

Method: The free carbon shall be determined by dissolving the compound in cold carbon bisulphide; filtering the solution through a Gooch crucible fitted with an asbestos pad; drying and weighing the insoluble residue; then igniting the crucible until all carbon is burned off, and weighing the residue (ash). The difference between the second and third weights is the free carbon.

B.—The fixed carbon shall be not less than 10% of the compound when the latter is freed of its free carbon.

Method: About 1 gramme of the compound shall be weighed into a platinum crucible, from $1\frac{1}{8}$ to $1\frac{1}{2}$ in. high. The crucible, with the lid on, shall be heated, first gently, and then until no more smoke and flame issue between the crucible and the lid. It shall then be heated for $3\frac{1}{2}$ min., to the full heat of the burner; then cooled and weighed. The crucible shall then be ignited until the carbon is burned off, and shall then be weighed again. The difference between these two weights shall be corrected for the amount of free carbon, and shall be calculated to the basis of compound purified of free carbon.

C.—When 20 grammes of the compound are heated in a flat-bottomed dish, $3\frac{1}{2}$ in. in diameter and $\frac{1}{2}$ in. high, for 5 hours, in an oven, the interior of which is maintained at a uniform and constant temperature of 105° cent., the loss shall be not more than 25% calculated on the compound corrected for its free carbon. The residue of such evaporation shall show a penetration not harder than 2 at 10° cent., and the melting point of this residue shall be between 40 and 60° cent.

Method: The oven shall be controlled by any suitable thermo-regulator, and shall have its full temperature before the compound is introduced. The calculation of the loss, obtained under this clause, is as follows: 20 grammes are weighed, the loss after the specified time of heating is, say, 4 grammes. This is 20% of the original compound, but the free carbon, as determined under Clause *A*, equals, say, 18%; hence 100% — 18% = 82%, and the 20% loss comes from 82% of the material, therefore it is 24.4 per cent. The penetration shall be measured by the Dow instrument or other standard machine, using a load of 100 grammes.

The melting point shall be determined as follows: 1 gramme

of the residue shall be evenly moulded around the bulb of a thermometer, which bulb shall be 1 in. long and from $\frac{3}{16}$ to $\frac{1}{4}$ in. in diameter, and the thermometer shall be suspended in a small beaker so that the bottom of the ball is $\frac{1}{2}$ in. above the bottom of the beaker. A paper cover shall cover this beaker. This beaker shall then be suspended in a large beaker, with sufficient water at a temperature of 5° cent. to reach nearly to the top of the inner beaker and be a depth below the inner beaker equal to the thickness of the layers on the sides; the apparatus shall be allowed to remain for at least 30 min. before any heat is applied. Heat shall then be applied to the bottom of the beaker in such a manner that the temperature of the water shall be raised 3° cent. each minute. The temperature recorded by the thermometer at the instant the ball reaches the bottom of the inner beaker is noted and shall be considered as the melting point.

D.—The compound shall be distilled in a retort until a loss equal to the loss obtained under Clause *C* is obtained. The percentage of fractional distillates to the whole distillation shall be as follows:

From 105 to 170° cent., not more than 5;
From 170 to 225° cent., not more than 25;
From 225° cent. to the end of the operation, not less than 70.

Method: 200 grammes of the compound shall be weighed into a retort (E. & A., 1 pint, No. 4521) the top of which is fitted with a "tee," as close as possible to the retort, and a condenser pipe from 18 to 24 in. long; the upper branch of the "tee" is used for the insertion of a thermometer, the top of its bulb being placed immediately below the main outlet of the "tee."

E.—The viscosity or consistency of the compound shall be such at 100° cent.:

That 50 cu. cm. shall flow through an Engler instrument in less than 100 sec.;

That when tested with a Lunge's tar tester, it shall not require more than ..... sec. to sink to the mark;

That when tested with a penetrometer, with a No. 2 needle, with a load of 100 grammes, it shall show a penetration not harder than ..... nor softer than .....

And it shall be such at 35° cent.:

That 50 cu. cm. shall flow through an Engler instrument in less than 350 sec.;

That when tested with a Lunge's tar tester, it shall not require more than 5 sec. to sink to the mark, reading to 140;

That when tested with a penetrometer, with a load of 100 grammes, it shall show a penetration not harder than ..... nor softer than .....

Method: The viscosity shall be determined by filling the cup to the mark with the compound, which has first been filtered through 100-mesh gauze to remove any large suspended particles. The consistency at ..... degrees, cent., shall be obtained with the Lunge tar tester, full description of which and method of using are given in Lunge's "Coal Tar and Ammonia," 3d edition, page 375. For penetration, any standard penetrometer, such as the Dow, shall be used, with a load of 100 grammes.

F.—If the compound is prepared from petroleum or natural asphaltic pitches, it shall be uniform in character, free from water or water-soluble material, dirt, or other adventitious material, and shall possess the following charactertistics:

The percentage of free carbon shall not exceed 1, and the solubility of the compound in cold carbon tetrachloride shall not be more than 3% less than its solubility in cold carbon bisulphide, and it shall be soluble in cold carbon bisulphide to at least 98%, when calculated to a basis of compound free of mineral matter.

Method: Same as before.

G.—The percentage of fixed carbon shall be not less than 5.

Method: Same as before.

H.—The percentage of paraffin shall not exceed 2.

Method: 100 grammes or less of the compound shall be distilled rapidly in a retort to dry coke. Of the well-mixed distillate, 5 grammes shall be treated in a 2-oz. flask with 25 cu. cm. of absolute ether; after mixing thoroughly, 25 cu. cm. of absolute alcohol shall be added, and the flask shall be packed closely in a freezing mixture of finely-crushed ice and salt for at least 30 min. The precipitate shall be filtered quickly by means of a suction pump, using a No. 575 S. & S. 9 cm. hardened filter paper. Rinse and wash the flask and precipitate (with 1 to 1 alcohol and ether mixture cooled to — 17° cent.) until free from oil (50 cu. cm. of washing solution is usually sufficient). When sucked dry, remove paper, transfer waxy precipitate to small glass dish, evaporate on steam bath, and weigh paraffin remaining on dish.

Calculation: Weight of paraffin divided by weight of distillate taken and multiplied by percentage of total distillate used from original sample, equals percentage of paraffin.

I.—When 20 grammes of the compound are heated in a flat-bottomed dish, 2¼ in. in diameter, for 5 hours, in an oven, the interior of which is maintained at 170° cent., the loss shall not be more than 2 per cent.

Method: The oven shall be maintained at the constant temperature by any suitable thermo-regulator, and shall have its full temperature before introducing the compound.

K.—When the compound is treated with 88° Baumé naphtha, at least 80% shall dissolve, and the solution in naphtha, when exposed on a plate of glass at room temperature until all the naphtha has evaporated, shall be decidedly sticky and not oily.

Method: 2 grammes of compound shall be placed in a 4-oz. oil-sample bottle, made up to 100 cu. cm. with 88° Baumé naphtha, and the whole well shaken until the compound is broken up. The bottle shall then be centrifugalized for 10 min.; 50 cu. cm. shall be withdrawn into a weighed flask; the naphtha shall be distilled by a water-bath, and the residue is weighed. Another 10 cu. cm. of this naphtha solution shall be run over glass and allowed to evaporate for 24 hours at room temperature; the residue shall be sticky.

L.—The viscosity or consistency of the compound shall be such at 100° cent.:

That 50 cu. cm. shall flow through an Engler instrument in less than 400 sec.;

That when tested with a Lunge's tar tester, it shall not require more than 5 sec. to sink to the mark, reading to 140;

That when tested with a penetrometer, with a load of 100 grammes, it shall show a penetration not harder than ..... nor softer than .....

And it shall be such at 35° cent.:

That ..... cu. cm. shall flow through an Engler instrument in less than ..... sec.;

That when tested with a Lunge's tar tester, it shall not require more than 100 sec. to sink to the mark, reading to 140;

That when tested with a penetrometer, with a load of 100 grammes, it shall show a penetration not harder than ..... nor softer than .....

Method: Same as before.

M.—When 50 grammes of the compound are evaporated for 5 hours in a dish, 2½ in. in diameter, in an oven, the interior of which is maintained at 205° cent., the residue shall be not less than 80% by weight of the normal compound. This residue shall be homogeneous and shall have a penetration at 10° cent. not harder than 3.

Method: The evaporation shall be done in an oven with a suitable thermo-regulator, and the full temperature of the oven shall be reached before the compound is introduced.

The penetration shall be obtained by the Dow or other standard instrument, using a load of 100 grammes.

General Note: As far as possible, specific descriptions of the instruments mentioned in this specification have been given. Slight differences in instruments occur, however, and in such cases the standard

instruments shall be those of the Commission's chemists. Re-tests of rejected material will be made, if desired, in the presence of a representative of the Contractor, and at the expense of the latter.

Pitch compounds which, in the opinion of the Engineer, have offensive characteristics, by reason of their odor or otherwise, will not be accepted.

Each lot of pitch compound furnished under this contract shall be subject to the tests mentioned, and shall show by these tests the characteristics specified. The tests will be made on samples taken from each lot of the compound as it arrives, and the results of the tests on the samples will be considered as characteristic of the lots from which the samples are taken. The rejection of a sample for any reason will cause the rejection of the lot from which the sample comes. The samples will be taken by the gallon from tank cars by the Engineer, or his authorized assistant. If the pitch compound is delivered in barrels, a pint will be taken from each of eight barrels selected at random by the Engineer from each car load of the shipment, and these pints will be thoroughly mixed together to form the sample to be tested.

All pitch compound, as well as all other materials, used under this contract, shall be subject to the approval of the Engineer, and pitch or other material disapproved by him shall not be used. Any disapproved material used shall be removed promptly and replaced by approved material, by and at the expense of the Contractor, on notice to him from the Engineer.

Sampittic Surfacing, Class A.

When the roadbed, after being prepared and shaped as herein described, does not consist of material in a finely divided state to a depth of at least 6 in., if deemed necessary by the Engineer, it shall be put in such condition by thoroughly plowing, harrowing, and cultivating to a depth of at least 6 in.

On the roadbed, prepared as herein described, the pitch compound shall be spread uniformly by using a sprinkling cart of a pattern approved by the Engineer, or by such other means as may be approved by him, and in a quantity not less than 1 gal., nor more than 1½ gal. per sq. yd. of surfacing. Unless otherwise approved in writing by the Engineer, the pitch compound shall be heated to a temperature of not more than 150° cent. and applied at a temperature of not less than 80° cent.

Immediately after an application of pitch compound has been made to a section of road, as above described, the pitched material shall be thoroughly turned over and mixed by using plows or harrows, so that none of the unmixed pitch is visible on the surface. A second application of pitch compound shall then be made, as before. The pitched material shall then be mixed thoroughly by using plows,

harrows, road scrapers, and such other means as may be necessary to insure a complete, uniform, and thorough mixing of the pitch compound and the sandy material of the roadbed. To secure this result, additional pitch compound shall be supplied, where necessary, by the Contractor, in the manner and under the conditions above described. Uniformity of mixing is most important and shall be secured, and pockets of unusually sandy or excessively pitchy material will not be permitted. When, finally, the roadbed material is mixed satisfactorily, in the opinion of the Engineer, the surface shall be carefully shaped, by raking or otherwise, to the cross-section, grades, etc., shown on the plans, due allowance being made for settlement.

If deemed necessary, and so ordered in writing by the Engineer, the roadbed shall be prepared as specified under the head of "Macadam Construction, Roadbed," and a thorough mixture of pitch compound and sandy gravel shall be spread on and applied to the prepared roadbed, instead of pulverizing the roadbed and sprinkling and mixing the pitch compound with it in place, as just above specified under "Sampittic Surfacing, Class A."

When "Sampittic Surfacing, Class B," methods are used by the Contractor, without written orders to such effect from the Engineer, the price to be paid for the surfacing will be that of "Class A," and only when ordered by the Engineer in writing will "Class B" price apply.

In the use of "Class B," the sandy gravel to be used, shall consist of at least 25% of stones which will pass a 1½-in. ring and not pass a ¼-in. ring, and, of the remaining 75% of the natural material, not more than 10% shall be loam or clay which will pass a 200-mesh screen. The Contractor shall secure and provide this material at his own expense from outside the road location.

The sandy gravel above specified shall be mixed with the hot pitch compound herein specified on a clean, tight platform of boards, or in a machine mixer of a pattern approved by the Engineer. Under no circumstances shall the mixing be done on the ground without a platform. The gravel shall be dry, before applying the pitch compound, being heated artificially at the expense of the Contractor, if necessary, to secure this condition. Unless otherwise directed in writing by the Engineer, the pitch compound shall be heated and applied to the dry gravel at a temperature of not more than 150°, nor less than 80° cent. The pitch compound shall in no case be applied to the gravel when the temperature of the latter is higher than 100° cent. The quantity of pitch compound used shall vary between 3 and 7% of the quantity of gravel with which it is to be mixed, according to the proportions of the various sized particles in the latter, and as determined by the Engineer, but in no case shall the quantity of pitch compound used be less than 6 gal. nor more than 14 gal. per cu. yd.

of gravel, measured loose. The pitch compound and gravel shall then be thoroughly mixed to an even color, by hand or by machine. After being thoroughly mixed, the pitched gravel shall be spread on the prepared roadbed evenly and to a depth sufficient to give a thickness, when thoroughly rolled and compacted as hereinafter described, of at least 6 in. If a greater thickness is made by the Contractor for any reason, no extra allowance will be made.

Rolling.

The pitched material shall then be rolled by a "tamping roller" of a pattern approved by the Engineer. This roller shall have toothed concentric rings, or shall be a drum studded with spikes, or shall be of such design as will insure the thorough compaction of the pitched material from the bottom up. The rolling shall be continued until the utmost degree of compaction is secured, and until the spikes or teeth of the wheels do not penetrate the surface more than 2 in. If deemed necessary by the Engineer, the road shall be sprinkled with sufficient water, during the rolling, to insure the thorough compaction of the surfacing.

Finishing Coat.

When, in the opinion of the Engineer, the pitched material shall have been compacted sufficiently, as above described, a third coat of pitch compound shall be applied, as hereinbefore described, and in quantity not less than ½ gal., nor more than 1 gal. per sq. yd. The surface shall then be lightly harrowed or raked, or both, to insure a thorough mixing of the pitch compound with the loose material remaining in the road, and shall be raked and trimmed to the cross-section and grades desired. The road shall then be thoroughly rolled, until firm and hard, with an ordinary steam roller, weighing not less than five tons. Any unevenness or depressions shall be remedied by the addition of properly mixed pitched compound and sandy material of a character similar to that in the roadbed, as may be deemed necessary by the Engineer. Should spots in the road show an excess of pitch under this last rolling, sufficient sandy material to absorb the pitch shall be dusted over them carefully and evenly.

Price.

The price agreed to be paid for sampittic surfacing will include all labor and material necessary to do the work as herein specified under pitch surfacing, and will also include the repairs necessary, in the opinion of the Engineer, for a period of two months from the day of the acceptance of the work, which repairs shall be made with the same materials and in the same manner as the construction above specified.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1114

A SYSTEM OF COST KEEPING.*

By Myron S. Falk, M. Am. Soc. C. E.

With Discussion by Messrs. P. L. Reed, W. C. Hammatt, Emile Low, Richard T. Dana, T. Kennard Thomson, F. H. Newell, William Murray Black, Guy W. Culgin, W. Boardman Reed, George Hill, Willard D. Lockwood, and Myron S. Falk.

The description of itemized costs of contract work always attracts some attention; unfortunately, the greatest amount of publicity has been given to the actual costs of unit items on construction work rather than to the bookkeeping methods used in obtaining those quantities.

It seems hardly necessary to call attention to the very small value that cost records may have to others than to those who gathered them and who realized and understood fully every local condition at the point of construction. There are some, however, who believe that all cost records have value, and that their publication, no matter in what form, will be a benefit. There is no doubt that the records of cost of completed work are useful to some slight extent to others than their compilers, but the greatest value of such records is derived during the time of their collection by the men who are doing the work.

By their use, a contractor can determine with reasonable accuracy the value of the work performed during any specified period; he can compare its cost with that of any other period, and he can determine

* Presented at the meeting of May 5th, 1909.

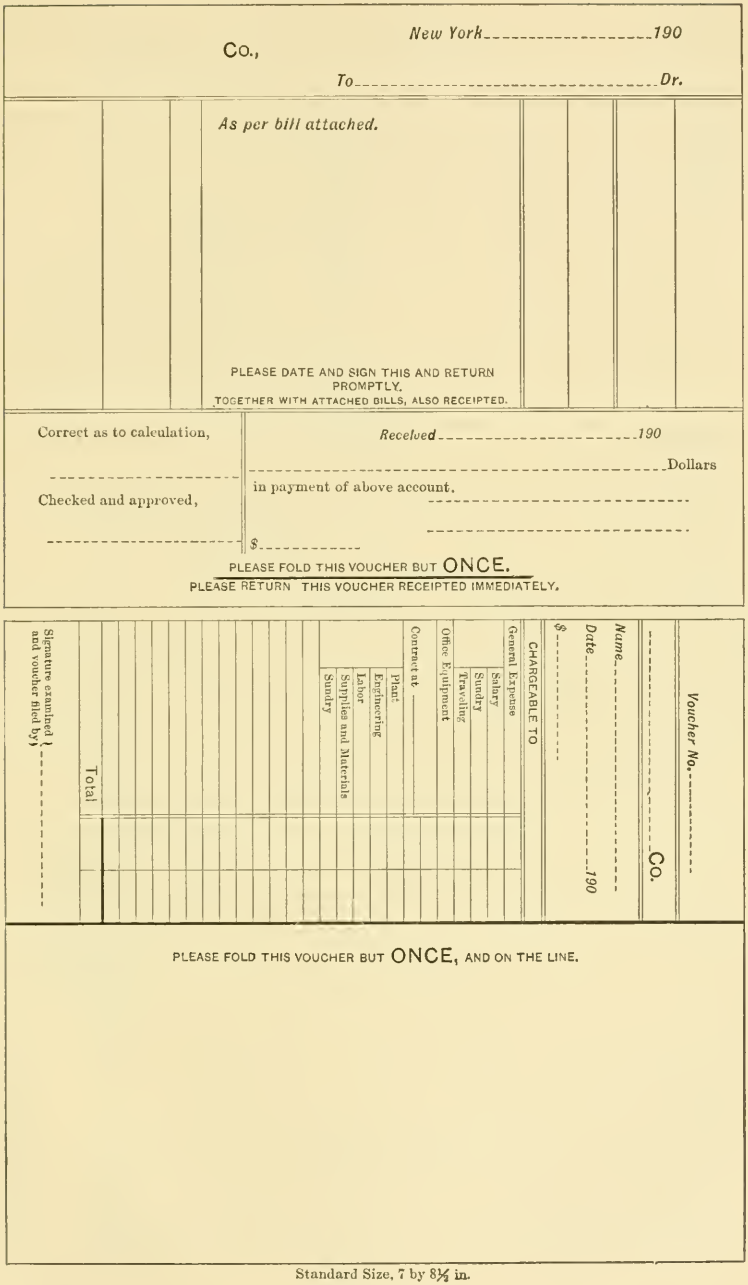
whether the efficiency of his force is increasing or decreasing and so take the necessary steps to keep his organization in good order. It must be common experience that the superintendent at the point of construction is always an optimist; that he gauges his output for any week by the best day's work, and estimates unit costs by that gauge; his memory is short with regard to delays and bad weather, and his estimate of the growth of work in the field is prone to error.

Cost records, therefore, have a distinct and important value to their compilers, and this paper, for which no special originality or singular merits are claimed as to the system of bookkeeping which it describes, is presented that others may describe their methods, with a view of developing some simple and uniform systems of accounting, so that a contractor may know for what purpose he is making expenditures.

The Accounting System.—The company keeps but one book, namely, a cash book; in this book there are entered on opposite pages the receipts and payments of money. The distribution of the payments to their various accounts is the basis of cost keeping.

Every payment, no matter of what kind or for what purpose, is made in the form of a blanket voucher, as shown by Figs. 1 and 2; each payment as made is numbered consecutively in the cash book, and this number appears on the voucher and on every bill, order, or blank which concerns in any way the payment in question; the tracing of orders, material received, etc., is checked by noting whether a voucher number is marked upon it.

On the back of the voucher (in the proper blank space), after the bill has been receipted, there is written the account or item against which the payment is to be charged. This payment may be charged against any item of any particular contract, or against any general or overhead expense account, such as traveling, rent, or telephoning. The charge on the back of this voucher is entered in the cost-keeping ledger, which is a loose-leaf book, a sample page of which is shown by Fig. 3. Each page represents one item, and particular attention is called to the left half of the page, which represents expenditures. These expenditures are itemized in two groups and a "Total"; the first column, headed "Labor," represents labor charges; the second column shows any and every other expense chargeable to the main item; and the third, headed "Total," shows the sum of the preceding two, whenever desired. It is evident that this page is the key to the



Standard Size, 7 by 8½ in.

FIGS. 1 AND 2.

Sheet No. 3

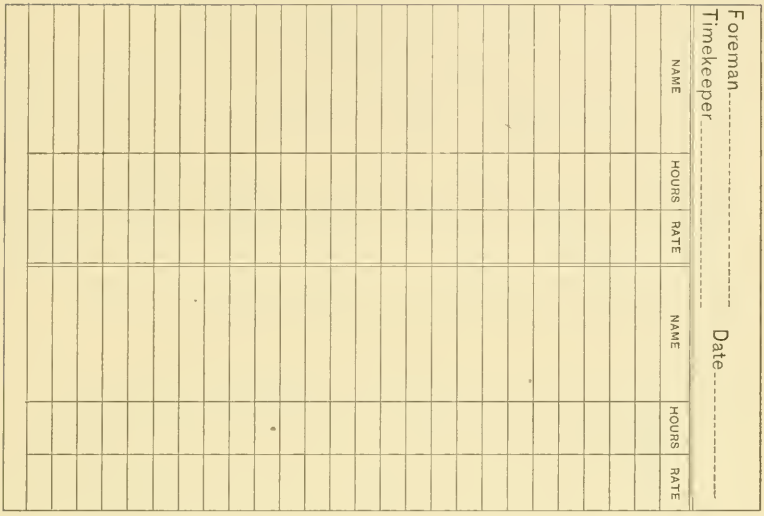
CONSTRUCTION CO. CONTRACT

CHARGE TO ITEM NO. 3. Eight-Axed Granite Masonry

DATE		VOUCHER NO.	EXPENDITURES	LABOR		TOTAL	DATE	RECEIPTS	TOTAL
Mar.	11		Unloading lighter Pier III	17 50					
"	12		loading for Pier II Course A	17 50					
"	13		Rain all day	6 45					
"	14		laid Pier III A 387 cu. ft.	36 52					
"	15		" " B.C. 237 " "	28 65					
"	19		Rain and snow	7 20					
"	20	624	F. Baldwin Manila rope		31 40				
"	"	630	Red Star Towing Co. towing		30 —				
"	"	631	O. J. Stephens — Coal		131 25				
			etc						

Standard Size 9 in. wide and 12 in. high.

FIG. 3.



ENGINEER'S DAILY REPORT
To be forwarded to main office every evening

COMPANY,

DATE
WEATHER
TEMPERATURE

LOCATION OF WORK..... SECTION No..... CLASS OF WORK.....
Work Commenced..... A.M. Work Ceased..... M. Work Recommenced..... M. Work Ceased..... M.

Class of Labor	Foremen	Laborers I	Laborers II	Laborers III	Laborers IV	Masons	" Helpers	Bricklayers	" Helpers	Carpenters	Timbermen	Dock Builders	Steam Engine Men	Firemen	Teams	Carts										Total
No. of Men																										
Total Hours Worked																										
Pay per Hour																										
Amount																										

ROSENDALE / PORTLAND } CEMENT USED ..... BAGS COAL RECEIVED

Material Received this Day. (Forward receipt tickets with this report.)

SIGN HERE

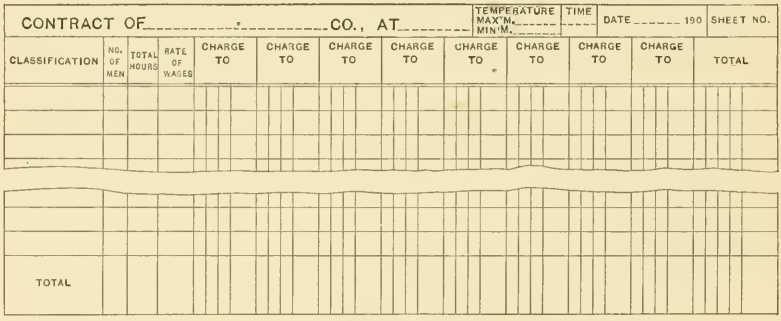
.....ENGINEER

Standard Size, 4 by 6 in.

FIGS. 4 AND 5.

entire system; the cost of labor is maintained entirely distinct from every other charge, and that cost is precisely the one most desired, as other costs, for plant, raw material, or anything else, can, as a rule, be determined or estimated without essential error.

Before describing the entries in this book, it is necessary to state that as soon as the company receives a contract, it prepares a list showing the items under which all expenses are to be subdivided. If the contract is based on unit prices, these items include the various units of the contract; for example, piles, or grillage timber, or waterproofing, etc., as well as items for plant erection, or plant removal, or plant maintenance, which cover expenses that cannot be charged against any one unit until the completion of the work. Again, many of the unit items of the contract are in turn subdivided.



Standard Size, 5 by 8 in.

FIG. 6.

As soon as a blanket voucher is receipted and returned to the company, it is charged against the proper item in the cost-keeping ledger, and is then filed, the only exception being in the case of vouchers for pay-rolls. As one pay-roll voucher covers either one or two weeks' work, it obviously cannot be entered in the ledger until it is subdivided into unit charges. This is performed in the field by the timekeeper, who uses the cards shown in Figs. 4, 5 and 6. Fig. 4 shows the pay-roll card for each day; each man's name or number, together with the amount earned by him, is entered upon this, and, on the reverse side (Fig. 5) is tabulated all the labor for the day. This tabulation is then carried forward to the card shown by Fig. 6, and is there itemized and charged against the various items of the contract. If the pay-roll is met weekly, seven of these cards

CONTRACT OF ____ Co., AT ____ TEMPERATURE MAX'M ____ MIN'M ____ TIME ____ DATE 8/29/08 SHEET NO. ____

CLASSIFICATION	NO. OF MEN	TOTAL HOURS	RATE OF WAGES	CHARGE TO Gravel Side Walk	CHARGE TO 2" Pipe and Rolling	CHARGE TO Asphalt Blocks	CHARGE TO Plant Const	CHARGE TO Maintenance	CHARGE TO #2 Concrete	CHARGE TO Curbing	CHARGE TO Ashlar Masonry	TOTAL
Foreman	1	8				(11)	5 00				(2)	5 00
Laborers	51	4 0 5/3	20	5 60	16 80	33 10	(32)		2 56 0			8 1 1 0
"	24	28 3/4		(34)	(42)	3 34	2 06			(32)	1 27	6 6 7
" 3	2	16	35			2 80		(45c.)	2 80			5 6 0
Masons	2	12		1 75	1 75				(12)		2 75	6 2 5
Blks	8	64	45 3/4				14 00	14 00				28 00
St Engines	2	16				4 2 0	3 75					7 7 5
St. Cutters	2	8	56 1/4							4 5 0		4 5 0
Curb Setters	2	8								3 75		3 7 5
Boy & Horse	1	8				3 60						3 6 0
Oscars "	1	8				2 00						2 00
Watchman	1	-		25	25	25	25	25	25	25	25	2 00
Timekeeper	1	-			25	25	25	25	25	25		1 5 0
Engrs	1	-		25	1 00	50	5 0	1 00	1 00	5 0	25 (OK)	5 00
TOTAL	79			85	20 05	5 0 04	25 81	1 5 5 0	2 9 9 0	9 85	4 52	$ 162.92

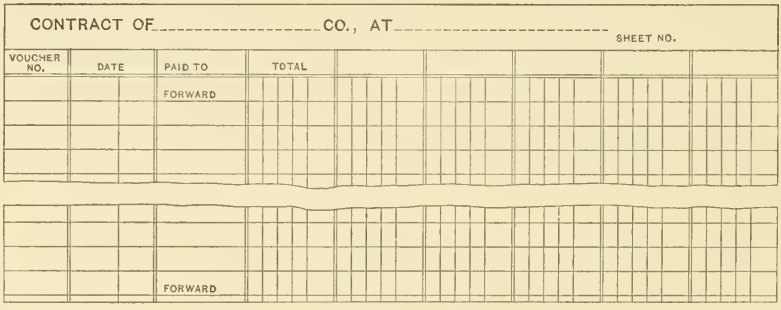
Laid 350 Sq. Yds. Bellford - Laid 350 Sq. Yds. 2" pipe and part 6 Paulings - Unloaded 2,375 o asphalt Blocks - Moved Stock House - Put on 61 1/3 Sq. Yds. of road foundation - Set 61 - Cut 15-16" - Planning and pointing Pier

Standard Size, 5 by 8 in.

FIG. 7.

must equal the total shown on the blanket voucher of the cash book. There is also written on the itemized pay-roll cost card (Fig. 6) the amount of work accomplished on each item; the quantities are obtained by the timekeeper each day from the various foremen without any difficulty and with comparatively small error. As an example, Fig. 7 is reproduced; this is an actual card turned in by the timekeeper. As soon as the pay-roll and blanket voucher are made up, the items on the cards representing that roll are entered in the cost-keeping ledger, as shown by Fig. 3.

The items in this book are totaled in pencil, at intervals of a few days or a week, in order to note the progress and cost of the work; each page is permanently totaled and checked in ink on the first day of each month, and checked against a supplementary card-system, which



Standard Size, 5 by 8 in.

FIG. 8.

records the total cost of any contract, in the condensed form shown by Fig. 8. On this card, each blanket voucher is also entered as soon as filled out, and is itemized into one of five general headings; usually these headings are (1) Labor, (2) Plant, (3) Material Remaining in Work, (4) Other Material, and (5) Sundries, there being five columns on each page. This supplementary card ledger is extremely useful in showing at any time the general divisions of expense.

To complete the description of the system, the card illustrated by Fig. 9 is shown. This card is the summary of seven of the daily cards shown by Fig. 4, and is used in making up the weekly pay-rolls.

It has been found that the cards shown by Figs. 4 and 6 might be combined in one card in order to save the time of the time-keeper, but the sheet resulting from the combination has been found

to be too bulky to be used on a stiff card, in which form all the records of the company are now kept, and, rather than use thin paper records, the present card system is maintained.

COMPANY, Time for Week Ending

Location of Work Section No. Sheet No.

Class of Work

Names / Date																								
S.																								
M.																								
T.																								
W.																								
T.																								
F.																								
S.																								
No. of Hrs.																								
Rate																								TOTAL
Amount																								

Note:- On back of this sheet, furnish description of work accomplished this week. SIGN HERE

Standard Size, 4 by 6 in.

FIG. 9.

As used by the company, the foregoing system has furnished the office force precisely the information which it needed at any time in order to trace loss of efficiency in the field; and the records of the completed work, particularly in respect to the item of labor, are in the form needed when other and similar work is estimated. The system described is that used by the Godwin Construction Co., of New York.

DISCUSSION.

Mr. Reed. P. L. Reed, M. Am. Soc. C. E. (by letter).—As the author points out, cost records are of greatest value to those who make them and at the time and place at which they are made. Their value diminishes rapidly with time, distance, and changing personnel, for, while it may be permanently recorded that a piece of work cost a definite sum, it becomes increasingly difficult to determine just what that piece of work was, and all that was involved in its construction. The numerator is known, but the denominator is often most uncertain, and the quotient is what is needed as a guide. Records involve the expense of preparation and the mental effort of examination and future reference, and, as costs are amplified, the expense gains on the utility, sometimes to the point where general conclusions, which might be of considerable value, are drowned in masses of details of slight transient importance, which rapidly lose their value until, in practice, the records are not found worthy of the time and mental effort required to consult them.

The deviser of a cost-keeping system, which, in some form, is almost essential to the conduct of any business where things are made, must curb his enthusiasm by considerations such as these, and stop before he has gone too far.

Referring to some of the details of the system described, which seems to be a very good one, the writer occasionally sees a voucher similar to Figs. 1 and 2, on the outside of one fold of which is printed the check upon which the bank makes payment. This seems to have some advantages, as the endorsement on the back of the folded voucher is likewise a receipt for the amount of the bill as summarized on one fold and distributed on the other, much as in the case of that illustrated by the author. The form would also be most convenient for auditing, though, possibly, not so popular with the banks.

The preparation of the time report, Fig. 4, on a fresh card or cards each day, with names, rates of pay, etc., would seem to involve an amount of clerical work out of proportion to its value. If entries are made day by day, the weekly pay-roll form shown in Fig. 9 apparently serves every purpose of that shown in Fig. 4, except to inform the head office daily of the name, hours worked, and rate of pay of each employee, which does not seem very important where the condensed statement of the force account by trades is sent in daily on the form, Fig. 5, and the names, etc., weekly, on the form, Fig. 9.

Where the force is large, or where the work of time and cost keeping is divided between timekeepers and cost clerks, it is necessary to assign numbers or other simple characters to the different sub-heads under which the work is divided, and to enter these characters opposite the names of employees on the time card, so that the labor charges can be properly distributed by one not in close touch with the work on the ground.

W. C. Hammatt, Assoc. M. Am. Soc. C. E. (by letter).—When in charge of various pieces of construction, the writer has always endeavored to keep close and accurate costs, in order to check, not only the unit costs of different classes by previous work of the same class, but also to present to the company, at the end of the work, an accurate and minutely itemized valuation of the work done, for inventory and insurance purposes. He has used practically the same system in his work as Superintendent of Construction for the Mountain Copper Company, at Martinez, the American Smelting and Refining Company, at Chihuahua, Mexico, and the Mammoth Copper Mining Company, at Kennett, Cal.; therefore, only one of these cases, for example, the construction at Chihuahua, will be described. Mr Hammatt.

The first step of the system involved giving a segregation number to each piece of work. This minimized the clerical work, and also gave convenient reference to ledger accounts. In this system of segregation whole numbers are used for the main divisions of work and decimals of various length for the sub-segregations under these divisions. This provided for a combination of all the decimals of a certain degree when segregations of lesser refinement were necessary for certain purposes. For example:

Construction Schedule.

General Expense:

01 Superintendence.
02 Surveying and drafting.
03 Office expenses.
04 Proportion, main office.
05 Temporary tracks.
06 Tools, push cars, concrete mixer.
07 Real estate.
08 Warehouse stock.
09 Warehouse expense.

Blast Furnaces:

10 Building.
11 Furnace No. 4, bustle pipe, settler, etc.
12 Changes in present furnaces.
13 Slag and matte equipment.
14 Furnace No. 5, bustle pipe, settler, etc.
15 .....
16 .....
17 .....
18 Connecting blast pipe.
19 Blast pipe in smelter.

(These sub-headings apply to all following headings.)

0.1 Grading.
0.2 Forms.
0.3 Concrete.
0.4 Superstructure.
0.5 Falsework.
0.6 Plumbing.
0.7 Wiring.
0.8 Painting.

Mr. Hammatt.

Converter Plant:

20 Building (including crane).
21 Converter No. 1 (including stand and tilting system).
22 " No. 2 (" " " " ").
23 Downtakes.
24 Flue.
25 Charge system.
26 Copper disposal.
27 Slag disposal.
28 Blast pipe.
29 Hydraulic system.

Relining System:

30 Building.
31 Relining pit (including tamper and crane).
32 Clay mills.
33 Clay and quartz bins.
34 Track and trestle to same.
35 Tunnel.
36 Drying stands.
37 .....
38 .....
39 .....

Charging System:

40 Tunnel.
41 Trestle.
42 Trackwork.
43 Equipment, charge cars.
44 .....
45 .....
46 .....
47 .....
48 .....
49 .....

Flue System:

50 Dust chamber, steelwork (including hoppers).
51 .....
52 .....
53 .....
54 Tracks.
55 New stack.
56 Equipment, cars, etc.
57 .....
58 .....
59 .....

Mr. Hammatt.

Power Plant and Blast Mains:

60 North addition (building).
61 South " (").
62 Receiver.
63 Changes in present blowers and connections.
64 Blower No. 4 and connections and motor.
65 " No. 5 " " " "
66 Blowing engine.
67 Blower No. 6, connection and motor.
68 " No. 7, " " "
69 Generating set No. 2.
70 Switch-board.
71 .....
72 .....
73 .....
74 .....
75 .....

Sampling System:

76 Temporary sampling room.
77 .....
78 .....
79 .....

Track System:

80 Standard gauge changes.
81 New standard gauge yard.
82 Slag tracks.
83 Lime track.
84 Track scales.
85 .....
86 .....
87 .....
88 .....
89 .....

0.1 Grading.
0.2 Track-laying.
0.3 Ballasting.
0.4 Switching.

Shops:

90 Machine-shop building and blacksmith shop.
91 " " plant.
92 Steel " building.
93 Compressor-motor and building.
94 Boiler-shop and round-house building.
95 " " " " " plant.
96 Carpenter shop building.
97 " " plant.
98 Electrical shop building.
99 .....

Mr. Hammatt. *Bins and Trestles:*

100 Main receiving bins.
101 Trestle approach to same.
102 .....
103 .....
104 .....
105 .....
106 .....
107 .....
108 .....
109 .....

Miscellaneous:

110 High-pressure pipe line.
111 Cement sheds.
112 Greek bunk house.
113 Drain tunnel.
114 Smelter stable.
115 .....
116 .....
117 .....
118 .....
119 .....

Standard Gauge Equipment:

120 Oil tank.
121 Locomotives.
122 Wrecking crane.
123 Cars.
124 .....
125 .....
126 .....

In regard to this list, it may be stated that it is faulty in its arrangement, due to the full plans for construction not being complete at the time the work was started. The writer believes in a more complete segregation of fixed and movable plant, for insurance and appraisal purposes, as a machine can be moved to a new site, while its foundation can not, and the superstructure of a building is subject to destruction and damage by fire, while its foundation is not.

In the matter of construction reports: The forms of two reports used for cost keeping from day to day, are given in Figs. 10 and 11. That shown by Fig. 10 was made out daily by the foreman for each kind of work done under his supervision, a separate report being made out for each segregation. At the end of the week the form shown by Fig. 11 was made out by the cost clerk from the data on Fig. 10,

and the measurement or estimate of each piece of work performed. The form shown by Fig. 10 was also used by the timekeeper as a check on his time, as the total number of man-hours or man-days should agree in both cases, and also the total in dollars and cents for the pay period. Mr. Hammatt.

As there is likely to be inaccuracy in progress measurements which are taken daily, or even weekly, it is well to combine the reports of several weeks. These inaccuracies will then disappear, and a truer calculation of unit cost may be made.

AMERICAN SMELTING & REFINING CO.
CHIHUAHUA PLANT

Daily report of labor on_____
for_____
Segregation_____
Date_____

NO.	EMPLOYEES	NO. HRS.	RATE	AMOUNT
	Foreman			
	Carpenters			
	"			
	Helpers			
	Mechanics			
	"			
	"			
	Helpers			
	Stone Masons			
	Brick "			
	Helpers			
	Engineers			
	Firemen			
	Plumbers			
	Helpers			
	Electricians			
	Laborers			
	"			
	Water boys			

FOREMAN

Standard size, 7 by 3¾ in.

FIG. 10.

AMERICAN SMELTING & REFINING CO.
CHIHUAHUA PLANT

Cost report for_____
_____on_____
Segregation_____
Ending_____

DATE	ACCOUNT	UNITS	RATE	AMOUNT
	Labor			
	do			
	do			
	do			
	do			
	do			
	do			
	Brick			
	Stone			
	Sand			
	Lime			
	Cement			
	Lumber			
	Cost per unit			

Standard size, 7 by 3¾ in.

FIG. 11.

This system had to be varied for the different conditions under which the construction work was conducted, for example, in Mexico, where the foremen were mostly illiterate, special men were employed for the cost keeping, and the forms differed slightly from those used in places and on classes of work where men of better mental capacity were employed.

Bills for materials of construction were distributed by the superintendent or cost clerk at the time of checking to the accounts where

Mr. Hammatt. they belonged. When bills could not be charged to their regular jobs, on account of the actual quantity of material going to each job being unknown, the total was charged to warehouse, and the different jobs debited and warehouse credited as the material was issued.

It may be added that the engineer generally works under difficulties in keeping accurate cost records, as the general idea among American employers is that such data are useless expense, and they will not allow the necessary clerical force to make them accurate and useful. The sentiment among most of them was expressed in the late Mr. T. S. Austin's remark to the writer that whether the brickwork costs $12 or $30 per 1 000, the work would go on until it was completed or the company "went broke."

Mr. Low. Emile Low, M. Am. Soc. C. E. (by letter).—The system of cost keeping described in Mr. Falk's paper is that used by a contracting company, and is really a compilation of expenses. It shows how the money was expended among different assumed items, and thus affords data for the detection of mismanagement in work of similar nature.

On construction work it is always interesting for the engineer-in-charge to know, at least approximately, what the work is costing the contractor. For want of absolute knowledge of the cost of some items, it may be difficult to ascertain the total cost, but even a knowledge of the cost of some of the items, as before stated, is of some satisfaction.

It may be stated with some assurance that, during construction, nearly every railroad company keeps some kind of a force account, which is rendered to the chief engineer, generally weekly, by his subordinates.

Some years ago, while the writer was in charge of some heavy railroad construction in Southwestern Virginia, he originated and put into effect a system of cost keeping, which showed monthly the cost to the contractor of various classes of work, the statements of which were submitted with the monthly estimates.

The system was extremely simple, and consisted essentially of three blank forms which constituted the basis for keeping the records.

On the railroad in question, each residency consisted of from seven to ten 1-mile sections, thus each residency ranged from 7 to 10 miles in length. The contractor's forces were counted daily by a timekeeper employed by the railroad company, which work comprised his whole duty.

A special timebook was prepared, a double page of which is shown by Fig. 12.

From an inspection of the timebook it will be noted that it is arranged to keep a separate record of each and every piece of work, no matter what it may be. It is also arranged to show the totals for each full week as well as for the partial week. Occasionally, there is a

NORFOLK & WESTERN R.R. CO. _____ DIVISION

DAILY STATEMENT OF FORCE EMPLOYED BY

_____ CONTRACTORS

ON _____ STATION _____

SECTION NO. _____

FOREMAN

DATE	DESIGNATION OF LABOR AND MATERIAL: 1	2	3	4	5	6	7	8	9	10
F										
S										
TOTAL										
S										
M										
T										
W										
T										
F										
S										
TOTAL										
S										
M										
T										
W										
T										
F										
S										
TOTAL										
S										
M										
T										
W										
T										
F										
S										
TOTAL										

DATE	DESIGNATION OF LABOR AND MATERIALS: 1	2	3	4	5	6	7	8	9	10
S										
M										
T										
W										
T										
F										
S										
TOTAL										
S										
M										
T										
W										
T										
F										
S										
TOTAL										

SUMMARY

DESIGNATION OF LABOR AND MATERIAL	FOR WEEK AND PARTIAL WEEK ENDING:						TOTAL	RATE	AMOUNT
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
TOTAL									

Standard size, 7 by 8½ in

FIG. 12.

Mr. Low. month which includes four full weeks and parts of two weeks, making space for six entries necessary.

The usual practice is to send in the force accounts weekly to headquarters, and the arrangement of the book facilitates this. At the end of the month there is a summary from which the cost of the work is obtained.

Of course, owing to the method used, the cost obtained is not absolute, as the force employed during the morning and afternoon may vary in numbers, the timekeeper passing over the work only once a day. Where absolute accuracy is required, more timekeepers would have to be employed.

As there are no printed headings, the spaces may be filled in as the nature of the work requires. Space is provided for ten different designations of labor and material, and in cases where there are more items, other pages can be used. It will be seen that the timebook is very flexible, and can be adapted to any contingency.

At the end of the month all work is classified, the form, Fig. 13, being used. The sample sheet shows columns for clearing, grubbing, grading, and masonry. This column is left blank, and the various classes of work are written in, using as many sheets as necessary.

Before the final classification, by sections, the location of each individual piece of work is entered in the column having the printed heading, "Sec." On the grading there may be as many as ten or more forces at work on a mile section; several culverts, bridge abutments, and piers may also be building.

The blank form, Fig. 13, may be used in making a compilation showing the cost for separate localities, or the totals for any one section may be entered, these totals being obtained by the addition of the various separate items.

Fig. 14 is a blank form showing the summary of all the work on a contract.

The main idea underlying the whole scheme is to make a monthly comparison with the engineer's estimate.

Referring to the timebook, Fig. 12, there is on a page the cost to the contractor of a particular piece of work, during the month, say, a bridge abutment. An estimate of quantities and cost has been made by the engineer in charge of this particular work.

The details of the cost to the contractor are transferred to the blank form, Fig. 13, the amounts being shown under the heading marked "Sec.," the "estimate" placed under the total, and the difference obtained, which will be more or less as the case may be. These statements then show in detail the expense and estimate of each particular piece of work.

Then a summary is made of each and every kind of work by sections (1 mile), and also a summary of the various estimates. These

summaries then show, mile by mile, the status of the various kinds of work. Mr. Low.

The engineer's estimate always shows the total cost of a section, and in order to make a proper comparison of all expense, another blank

_____ RAILROAD CO.,
COMPARATIVE STATEMENT,
ESTIMATE vs. EXPENSES

RESIDENCY NO._____ ESTIMATE NO._____
SECTIONS NOS._____ _____ DIVISION
MONTH OF_____ _____ CONTRACTOR

	CLASS OF LABOR	RATE	SEC. NO.	AMOUNT	SEC. NO.	AMOUNT	SEC. NO.	AMOUNT	SEC. NO.	AMOUNT
CLEARING	Foremen									
	Laborers									
	Teams									
	Total Labor									
	Estimate									
	Difference									
GRUBBING	Foremen									
	Laborers									
	Teams									
	Total Labor									
	Estimate									
	Difference									
GRADING	Foremen									
	Laborers									
	Teams									
	Blacksmiths									
	Carpenters									
	Total Labor									
	Superintendence									
	Explosives									
	Total Expense									
	Estimate									
	Difference									
MASONRY	Foremen									
	Stone Cutters									
	Masons									
	Laborers									
	Teams									
	Total Labor									
	Estimate									
	Difference									

Standard size, 8¼ by 10½ in.

FIG. 13.

form is needed, which shows a summary of all the labor, superintendence, explosives, stone, sand, cement, timber, iron, bolts, etc., this being the total cost of all the work in a section.

Mr. Low.

RAILROAD COMPANY,

DIVISION ______ DIVISION ENGINEER.

ESTIMATE NO. ______ 190__

COMPARATIVE STATEMENT
ESTIMATE VS. EXPENSES ______ CONTRACTOR.

RES. NOS. ______ TO ______ INCL.

SECS. NOS. ______ TO ______ INCL.

SECTION	CLASS OF WORK	LABOR	SUPERINTENDENCE	EXPLOSIVES	STONE, SAND, CEMENT.	TIMBER, IRON, BOLTS.	TOTAL EXPENSES	GROSS ESTIMATE	GROSS ESTIMATE: MORE LESS THAN TOTAL EXPENSE

Current									
Previous No.									
Total to Date									

Standard size, 10¼ by 8¼ in.

Fig. 14.

FORM No. C.E.______

CONSTRUCTION DEPARTMENT.

RAILROAD COMPANY.

______ DIVISION.

COMPARATIVE STATEMENT.

ESTIMATE VS. EXPENSES.

RES. NOS. ______ TO ______ INCL. ______

SECS. NOS. ______ TO ______ INCL.

ESTIMATE NO. ______

______ 190 ____

SUMMARY: CONTRACTOR

	DOLLARS	CTS.
Labor		
Superintendence		
Explosives		
Stone, Sand, Cement		
Timber, Iron, Bolts		
Total Expenses		
Gross Estimate		
Apparent *		

* GAIN OR LOSS

Total Expense		
Net Estimate		
Apparent		

EXTRA WORK

Amount plus 15 Per Cent		
Force Account		
15 Per Cent		

Certified By

______ DIVISION ENGINEER

Standard size, 3½ by 8¼ ins. Back of Form shown by Fig. 14

Fig. 15.

These totals, shown by Fig. 15, may be readily obtained by using the form shown by Fig. 14, for the purpose of tabulation, as the main items are all placed in separate columns, and can be easily added. In some quarters objection is made to keeping an accurate account of the forces employed by the contractor and the tabulated cost, the main reason assigned being that the engineer's estimate is influenced thereby to some extent. This need not be, as the cost to the contractor is not generally known until some time after the estimate is made out. In most public works nowadays there is no classification of excavation, so there are no grounds whatever for manipulation, although there might be under the classification method of dividing excavation into earth, hardpan, and loose and solid rock. Mr. Low.

Again, the contractor's costs may be tabulated wholly in the division engineer's office, or even in the office of the chief engineer, he being furnished with duplicate copies of the timebooks, which, as before stated, form the basis of the whole system described.

The writer is a firm believer in keeping costs of contractor's operations, for the very important reason (and almost the only one), that it affords some tangible evidence of fixing suitable unit prices on future work, instead of using that very undesirable makeshift, guessing at them.

Richard T. Dana, M. Am. Soc. C. E. (by letter).—The author states that "it seems hardly necessary to call attention to the very small value that cost records may have to others than to those who gathered them and who realized and understood fully every local condition at the point of construction." Apparently, he assumes that it is not possible to record the local conditions with sufficient thoroughness to make such records of value to a man who has not seen the site of the work. Such an assumption involves the further proposition that it is possible to appreciate conditions which it is impossible to express or describe in writing. If the writer is correct in this interpretation of the author's meaning, the author's position is untenable. It is generally accepted that in shop work the conditions can be sufficiently well recorded as to have resulted in the reduction of the art of cutting metals, for example, to almost an exact science.* Mr. Dana

In out-of-door work there is necessarily interference by the weather, by variation in the conditions of the materials to be handled, by accidents to large units of equipment, and by a considerable number of other causes which do not obtain in the shop. These causes, however, are such as to admit of classification, and it is entirely possible to obtain fairly approximate quantitative expressions for their comparison. The outside field has a great advantage over the shop in that

* Note the papers by Mr. F. W. Taylor in *Transactions*, Am. Soc. Mech. Engrs., Nos. 1003 and 1119.

Mr. Dana. the aid of photographs can be enlisted, and, at an almost infinitesimal cost, photographic records, which are more accurate than the eye and much more durable than the memory, can be obtained, and these records can help out the written notes so greatly as to enable the compilation of practically complete information for future use.

The author's assumption that a man must have seen work done in order to make cost records of it of value to him, means that his memory—his uncertain, hazy, and, perhaps, prejudiced memory—is to be trusted in preference to cold, hard, statistical facts. The writer's experience has been altogether in the opposite direction.

In the third paragraph, the author states that by the use of cost records in the field a contractor can with reasonable accuracy compare the cost of work performed in any specified period with that of any other period. As the local conditions necessarily vary from time to time, it seems difficult to appreciate why the cost from period to period can be compared with benefit, when, according to the author's statement in the preceding paragraph, cost records have small value to others than to those who gathered them, unless the contractor is going to keep the same superintendent on the job from start to finish.

The author has given some blanks showing the method of obtaining cost in the field. It appears as if he had endeavored to combine a cost-keeping system with a bookkeeping system. The bookkeeping system is based on the use of only one unit, the dollar, while cost keeping, as the term has been used in recent years, involves the recording of efficiency, and may utilize any of a considerable number of units. Thus, the cost of drilling may be expressed in minutes per foot; the cost of hauling material may be expressed as the reciprocal of the expression "tons per team-day," and so on. The writer prefers to consider cost keeping as simply a method for recording efficiencies, using whatever units seem most convenient at the time, and to confine it to a class by itself, not allowing it to interfere in any way with the bookkeeper's work, thus avoiding the imposition of a considerable amount of burdensome labor upon the bookkeeper, and using the units most suitable for the case in hand.

Because rates of labor vary in different localities at the same time and at different times in the same locality, the dollar is not even approximately a true measure of efficiency, and the writer prefers to use, as a standard for comparison, the United States Reclamation Service unit of a man-day.

Mr. Thomson. T. Kennard Thomson, M. Am. Soc. C. E.—The speaker is a firm believer in cost analyses, provided all the facts are known, including the personal characteristics of the contractor and his superintendent. For all know that two contractors can take exactly similar contracts under exactly similar conditions as regards labor, material, location,

etc., and at the same prices; and while one contractor will make a good profit, the other will sustain a heavy loss, just as one man can start a grocery store or a restaurant and make his fortune, while another man, with the same capital, store, and stock, will go bankrupt. Mr. Thomson.

Again, the same contractor's profit or loss will depend largely on his superintendent—unless he acts as his own superintendent. As an example, a well-known contractor had a steam-shovel job with a $5 000 superintendent who left when the job was half through, and a $3 000 man was put in his place. The second man, with exactly the same labor, cars, tools, material, etc., only turned out 60% as much material as his predecessor.

Two of the speaker's clients are contractors—though not competitors—in similar lines of business, and he always advises one to bid 30% higher than the other, and, even then, he feels sure that the first will make a bigger profit than the second.

While cost analysis, therefore, is absolutely necessary, and is much used by the speaker, it would generally be disastrous for a contractor to bid on work in which he was inexperienced, on the strength of the cost analysis made by some one else, and, while the speaker is in favor of cost analysis, he generally wants to know who made it and who will use it.

F. H. Newell, M. Am. Soc. C. E. (by letter).—The following comments, prepared by Mr. V. C. Croissant, are offered with the hope that they may be of value. Mr. Newell.

A careful reading of Mr. Falk's paper leads to the conclusion that the system described is for use on work which is highly centralized. The contracts are evidently for compact pieces of work in a city. The opening paragraphs state very clearly the real value of cost-keeping data in the great majority of construction operations, and are especially pertinent to those for which this system is applicable. The method described would result in accurate data covering prime costs of any class of work in which labor was the principal cost element.

It should be noted that there are two sources of error in cost accounting which seem to be almost impossible of complete elimination. With the presence of possible errors due to either or both of these causes, the results are practically valueless to any contractor except (as stated by Mr. Falk) the person actually preparing the data. Even he may be so deceived by his own calculations as to find the bankruptcy courts eventually his only relief. These sources of error are:

1. The substitution of estimates for certainties, in the case of the engineer or proprietor who is so thoroughly impressed with the value of direct and prompt information that he uses assumptions (in many cases purely guesses) for actual mathematical facts. Such a man

Mr. Newell. gathers daily all the data possible, and, because of a lack of system or of a comprehensive plan, fails to consider many items, such as unpaid purchases, unpaid labor, depreciation on plant, interest on investment, the value of his own time, and supplies consumed which are not measureable in the completed units of work, but which, nevertheless, are fundamental and positive cost elements. His main ambition is to "know from day to day how things are going." To do this, he arrives at theoretical results by a series of allowances, the component elements of which are not certainly known. He may guess at them, or he may omit them entirely. His hypothesis may be satisfactory where the work to be done is small, and highly centralized, and when the engineer making the estimates is of large experience and excellent judgment.

2. The delay for accuracy which occurs with the bookkeeper or cost-keeper who is so professionally proud of his work, and so short-sighted, as to make absolute accuracy his main concern. Such a man insists on the results being unassailable from any and every angle; the figures must "balance," or "square into" everything that bears on the accounting of the firm. This makes for accuracy—eventually—but the results are largely historical, and, after being neatly typewritten and "tied into" all related statements, are allowed to see the light of day long after the evils which they might have corrected are forgotten by the "man on the job." They are simply the autopsy of a dead transaction, not a diagnosis of the progress of a vital case.

The plan presented by Mr. Falk is one which requires a single book, namely, the cashbook. It would appear that all liabilities must be paid immediately; and that everything purchased in the way of supplies must go into the work immediately. If such is not the case, then future liabilities will not reach the cost accounts until the supplies represented are paid for. If supplies are purchased against a future need, they will be charged in the month paid rather than in the month used.

A cashbook, of course, cannot be used to record estimated depreciation on equipment used from month to month. If the work is done largely by expensive equipment, this important element of cost, depreciation, is overlooked. Interest upon investment would be entered from time to time if money was borrowed and interest paid at the bank. If the capital is actually paid in by the proprietors, and, consequently, no regular interest payment is made, then the cashbook would not record the legitimate earning on this capital to which it would be entitled. The old accounting question of whether bookkeeping should deal with cash receipts and disbursements, or whether it should deal with the question of values received and expended, whether paid for or not, is the one which really comes to the front. It was settled long ago in favor of the latter method.

Mr. Newell.

For a small business, the cashbook may be the only record necessary, but for operations which are extensive, it is, perhaps, the smallest part of the necessary bookkeeping records. The same rule may be laid down to decide whether or not cost-keeping shall become a part of bookkeeping. In small operations, it is quite possible to arrive at very accurate costs by a system of card records entirely independent of bookkeeping, but, for large works, the elements of cost are so numerous that a well-defined automatic system, governed or controlled by analytical accounting methods, must be adopted in order to insure complete records.

In the United States Reclamation Service a system has been adopted in which an attempt has been made to harmonize the views and serve the purpose of both the engineer and the accountant. In all Government work it is necessary, in addition to having the available results for the immediate use of engineers, foremen, etc., to make a permanent record of costs, since that work is subject to investigation by commissions, and by the public; and the expense of construction must be brought within a specific appropriation or allotment of funds, which corresponds to a commercial contractor's bid price for a given undertaking.

The system adopted by the Reclamation Service has been devised in order to place in the hands of the man locally concerned a complete record, which is available for his inspection from day to day, and shows the prime cost of all work. This prime cost takes up the charges for all labor, material, and supplies used; these records are entered daily, and, by the use of the adding machine, totals under any classification of expense, or for all classifications under any feature, can be known in a few hours. After the local cost-keepers have finished this tabulation the results go to the bookkeepers, who add the top extrinsic costs, such as administration, depreciation, and all the other expenses, which are unknown to the timekeepers and storehouse clerks. These are finally assembled in the project offices, and monthly statements for each feature are transmitted to the general office in Washington. When any large, or important feature is finally completed, the project engineer prepares from these local records a cost report showing the cost by units of work done, which is analyzed into all the elements of labor, material, supplies, power, depreciation, superintendence, general expense, etc.

By the method used in the Reclamation Service, the principal machinery for assembling costs is:

1.—An Account Number Book.—Each feature or job of work is assigned a set of numbers, as many being reserved as will be necessary to give each classification of expense a number. The following is an example:

Mr. Newell.

Dam for reservoir.

260 Superintendence and engineering.
261 Labor, Foremen.
262 " Masons.
263 " Cranemen.
264 " Teamsters.
265 " Timekeepers and clerical.
266 " Laborers.
267 " Animals owned and hired.
268 " Blacksmiths.
269 " Drillermen and machinists.
270 Supplies, Cement.
271 " Powder, dynamite, fuse, etc.
272 " Drill steel.
273 " Lumber.
274 " Power.
275 " Miscellaneous supplies.
276 " Labor and repairs.
277 Employers' liability.
278 Depreciation on equipment.
279 General expenses.

2.—Timebooks.—These books are ruled so that the time of each employee may be shown for each class of work performed. When the timekeeper takes time, he makes the proper notation, indicating the hours worked and the class of work.

Fig. 16 is an illustration of a timebook adapted for this purpose.

3.—Requisitions.—All supplies, materials, etc., are issued from storehouses at cost plus freight and a percentage addition to cover handling and storehouse expense. For this purpose a requisition blank, Fig. 17, is used. Each foreman is supplied with a list of account numbers which are allotted to the features of work in his immediate charge. When he makes up a requisition, he indicates, opposite each article ordered, the classification to be charged, by inserting the account number assigned to that classification. The storekeeper enters on the requisition the unit price and total value of supplies issued.

4.—General Classification Book.—This book, Fig. 18, is used to assemble the items of expense under each classification. Each folio is ruled with ten columns, and the columns are numbered from 0 to 9. The first folio is not numbered, and the columns 0 to 9 will represent the classification indicated; the second folio is numbered 1. Reading the column numbers as the units with the folio number as the tens, the columns on folio No. 1 will assemble the charges against classifications Nos. 10 to 19. Any number of account numbers can be added by inserting additional folios, as this is a loose-leaf book. There are thirty-one horizontal lines—one for each day of the month—and a few additional for special entries at the end of the month, as depreciation, interest, etc.

7–595

SHEET NO. _____ TIME BOOK _____ 19 _____

(Month) (Feature) 6–1191

NAME NO.	NAME OCCUPATION	ACCOUNT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Left page, Size 8 by 5¼ in.

Time and rate of pay correct:

(Signed) _____ (Engineer)

6–1191

CARRIED TO NEXT SHEET

26	27	28	29	30	31	TOTAL TO	TOTAL TIME	RATE Bro't from previous sheet	AMT. EARNED	TOTAL EARNED	MEAL TKTS.	ORDERS ON STORE	RENT AND HOSP.	TOTAL DEDUCTIONS	AMOUNT DUE

Right page, Size 8 by 5¼ in.

FIG. 16.

Mr. Newell.

DEPARTMENT OF THE INTERIOR
U. S. RECLAMATION SERVICE

REQUISITION

No._____

_____ *PROJECT*

_____ *19*

To STOREHOUSE CLERK:

Please furnish the following on account of the _____.

_____ feature:

ACCOUNT NO.	QUANTITY WANTED	QUANTITY FURNISHED	ARTICLES	UNIT PRICE	TOTAL
	Original (on white paper) goes to cost keeper				
		for entry in classification book			
	Duplicate (on pink) remains with storehouse				
		clerk for his protection			
	Triplicate (on yellow) is returned to foreman				
	as an advice of cost of goods furnished				

Deliver to _____

For forwarding by _____

Wagon Bill of Lading No. _____

(Signed) _____

_____

Received the articles above listed *as furnished*

(Signed) _____

_____

Standard size 5⅜ by 7⅝ in.

FIG. 17.

_____FOLIO DEPARTMENT OF THE INTERIOR UNITED STATES RECLAMATION SERVICE 7–580

GENERAL CLASSIFICATION SHEET

MONTH OF _____ 190 FOLIO_____

DATE	0	1	2	3	4	DATE	5	6	7	8	9
1						1					
2						2					
3						3					
4						4					
5						5					
6						6					
7						7					
8						8					
9						9					
10						10					
11						11					
12						12					
13						13					
14						14					
15						15					
16						16					
17						17					
18						18					
19						19					
20						20					
21						21					
22						22					
23						23					
24						24					
25						25					
26						26					
27						27					
28						28					
29						29					
30						30					
31						31					
Freight and handling						Freight and handling					
Time book distribution						Time book distribution					
Direct charges						Direct charges					
Journal Vouchers						Journal Vouchers					
TOTALS					6–747	TOTALS					6–747

Standard Size of page, 8 by 10¼ in.

FIG. 18

Mr. Newell. The amount of charges appearing on requisitions is entered daily in the respective columns, and the earnings of employees, as shown by timebooks, may be thus noted. The foreman or engineer wishing to know the cost of work on any particular feature at any time has only to ask the cost-keeper to add up the columns representing the classifications assigned to that feature, and he will have the total cost for labor and supplies expended to that date.

At the end of the month these sheets are removed from the binder and sent to the bookkeepers, who add the top costs and post the total for the month to the cost ledger which contains all charges for previous months, thus making a final completed record.

With the detailed analysis, as accumulated in this manner, the engineer can make a complete cost statement in minute detail or, if he prefers, in general terms, by combining several analogous classifications.

There are many other accounting phases which the writer has not mentioned herein, as the purpose is to treat of a method of cost keeping. Any accountant can fit the general plan above described into a well-organized bookkeeping system.

Mr. Black. William Murray Black, M. Am. Soc. C. E.*—It has been a surprise to the speaker to find that some of the technical journals seem to place a slight value on the keeping of cost data and a still less value on the publication of technical information of this class. He believes that cost data should always be kept, and, further, that such data, when properly kept and tabulated, are of great value, not only to the compiler, but also to all who are engaged in work of a similar character. The bare data should always be accompanied by a brief statement of the conditions influencing the cost, so that they may be a guide for later work.

It is unnecessary to draw attention to the fact that the very keeping of cost data implies a close supervision over work, and leads to the careful consideration of the items making for expense. In the case of contract work, a knowledge of the cost is of great value to the supervising engineer. Not only will it enable him to make later contracts more understandingly, avoiding the nearly equally bad errors of allowing excessive profit to the contractor or of making a contract for less than its cost, but also in case of disputes as to the true meaning of the contract, it will enable him to act justly and, not infrequently, either avoid a suit at law or place himself on good ground for meeting one. Further, it will enable the engineer to judge when work can be done most economically by contract and when by hired labor. Where work cannot be supervised closely by the responsible engineer, a daily detailed report of work done is a most efficient aid.

* Colonel, Corps of Engineers, U. S. A.

The forms on which cost data are kept must vary with the class of work. One principle is of general application: Make the clerical work to be done in the field as small as possible. Let the forms be simple. Let them be printed and written in copying ink or otherwise prepared so as to be readily duplicated, and have the field record books simply duplicate copies of the reports sent to the home office. Mr. Black.

GUY W. CULGIN, ASSOC. M. AM. SOC. C. E.—Mr. Falk had treated the question mainly from the standpoint of the contractor and his engineer, neglecting to consider the difficulties encountered by the engineer representing the first party to the contract in any attempt to ascertain what the work costs the contractor, and the solution of those difficulties, if any exist. Mr. Culgin.

Among the reasons which make it advisable to keep a record of the cost of the work, the following are suggested:

a.—He should be able to protect his client in case any claims arise, as it might be necessary to have definite figures to meet them, either in arbitration or before a court of equity.

b.—He, as well as the contractor, should know whether or not the latter is making a fair and reasonable profit.

c.—It is the only method by which an engineer can learn the true value of work and be able at any time to guard his client against entering into a contract at a figure unfair to either of the contracting parties, or in which the prices may be unbalanced to an unreasonable extent.

Some of the difficulties which the engineer meets in his attempt to obtain the true and complete cost of the work are:

1.—Difficulty in getting the actual time of the men and teams—men being frequently chargeable to the contract, although not present on the work, and possibly unknown to the engineer.

2.—Not knowing the true wage of each employee, nor knowing necessarily which are on broken time and which are on straight time.

3.—The impossibility of knowing the cost of the various materials and supplies to the contractor. The fact that these are not necessarily purchased at current market prices increases the difficulty.

4.—Not knowing the amount invested in plant, and the proper charges to be made against a particular contract in order to cover interest charges on plant and cost of up-keep and depreciation.

5.—Not knowing the cost of liability insurance (public and employee), fire insurance, contract bond, and, in some cities, bonds for blasting, street opening, etc.

6.—Not knowing the fixed charges of the contractor's organization, which are applicable to the contract in question. This item usually includes general offices, rent, and other expenses, also salaries of executive and clerical forces. These fixed charges are usually fairly uniform from year to year, and must be divided proportionately against

Mr. Culgin. the various contracts by some rule, which, while fixed, must be more or less flexible.

The paper and discussions have opened a very important subject, and the speaker trusts that the result will be some standardization of methods of cost keeping, by which the effects due to the peculiarities of each contract and the personal equation of the engineer may be reduced to a minimum. He believes, however, that it will be impossible to produce results which will be of much value to any one other than the compiler and those familiar with that particular work.

Mr. Reed. W. Boardman Reed, M. Am. Soc. C. E.—While engineers have always been in the habit of keeping data with reference to the cost of the material and labor entering into work of which they have had charge, oftentimes they have not kept their estimates in sufficient detail and with sufficient clearness to be of value for reference to others. Furthermore, the estimates have generally included field costs only, and have not taken fixed charges sufficiently into account, that is, they have not been accurate as far as such charges are concerned. This is a matter which should certainly be considered in making any estimate, whether preliminary, previous to construction, or for the purpose of arriving at a fair cost of reproduction. Depreciation, interest, taxes, and insurance upon a plant necessary to do the work should always be considered, and, therefore, in estimating the value of a piece of work, the value of the plant and the fixed charges on the same, should be considered.

In the past, the cost data kept by engineers have been largely for the purpose of reference in making estimates for future work which they might be called on to do, but with the advent of Government regulation of public service corporations, it becomes very necessary to be able to make, not approximate, but accurate estimates of the value of tangible property, and what it would cost to reproduce the same, as of various dates. In fixing freight and passenger tariffs, public service commissions are governed largely by the actual value of the property involved, which is also true of tax commissions in fixing taxes; and the speaker believes that engineers, in conjunction with the experts of the interstate commerce commissions and, possibly, the experts of the various State public service commissions, should design a standard system of cost keeping, which would greatly simplify the adjustment of disputed questions between corporations and various public service commissions.

During the past four or five years, there has been much litigation with reference to tax assessments, many investigations having been made by public service commissions in the City of New York, and though the corporation engineers had fairly accurate data with reference to costs, these were not based on any standard system of cost keeping, and, therefore, were not recognized by the commissions.

In addition to cost keeping on construction work, engineers having charge of operation or maintenance should keep a careful record of the cost of repairs and the length of life of various classes of material, so that an accurate estimate of depreciation may be made. Any system of keeping such records should be worked out in conjunction with experts of public service commissions. If this could be done, it would lessen materially the time required for settling questions with reference to tariff and taxes. Mr. Reed.

George Hill, M. Am. Soc. C. E. (by letter).—Every member of the Society who presents a workable solution of a problem, and especially one of such importance, is entitled to the thanks of the members for so doing, and therefore the writer feels that on so important a matter as cost keeping Messrs. Falk, Hammatt, and Lowe have done well to contribute of their experience. Mr. Hill.

The attempt has frequently been made to solve the problem in some conventional or semi-conventional manner, usually without success, for the reasons that there existed:

a.—A lack of appreciation of the requirement for simplicity;

b.—A lack of appreciation of the fact that the information required is a combination of figures and the combinations are constantly changing;

c.—The general belief that cost keeping is something different from bookkeeping, instead of being intelligent bookkeeping.

If the accounts of any piece of work can be kept so as to meet, on the one hand, all the requirements of bookkeeping, and, on the other hand, all the requirements of cost keeping, the problem is in the way of being solved.

The real and only purpose of bookkeeping is to show the receipt and disbursal of money in an accurate manner. If this is performed so that, with a minimum of clerical work, clerical and arithmetical errors can be readily detected and eliminated, it is good bookkeeping.

When the next step is taken, and the memoranda of disbursal show for what the disbursal was made, this is beginning cost keeping.

If this is done in sufficient detail and in such a manner that the summations of two or more groups can be readily combined, the problem of cost keeping is solved.

If vouchers, checks, and bills are arranged so that they can be readily examined and compared with the entries, this provides for an accurate and inexpensive audit, and meets completely all the proper requirements of bookkeeping, cost keeping and auditing. The writer would emphasize the word "proper"; there are in use systems which are very complete but are so burdensome that the facts cannot be recorded and transcribed until long after their usefulness has vanished, and they are so full of detail as to blind the mind completely to their

Mr. Hill. true significance. Knowledge of costs should be a weekly matter, and action should follow promptly.

It is a good thing to know that concrete 5 in. thick, placed in forms, cost on a certain job an average of 20 cents per sq. ft., but it is more important to know that Brown's gang laid it for 18 cents, while, with Smith's gang, it cost 22 cents, under the same circumstances.

While it is possible to predetermine the general lines along which costs will be required, two-thirds of the questions asked in regard to costs will call for summations of items other than those originally contemplated, and the same question will rarely be asked twice; consequently, the problem which the writer has attempted to solve is not a simple one. He has been engaged for many years in executing work on a fixed profit basis, and has had experience with the accounting systems of a wide range of clients, and, as a consequence thereof, has been compelled to devise a system of his own. Practical experience with this system has demonstrated its applicability over a wide range of subjects in a satisfactory manner. It is hoped that a description of it will be of interest to the Society.

Although the system presents a method of keeping the exact cost of a piece of work, and is therefore in the nature of bookkeeping, it is not bookkeeping in the conventional sense, but an orderly arrangement of memoranda which are kept so that any cost question which may be asked during the progress of the work, either of a detail or of the entire work, can be answered, either immediately or in a few minutes. The memoranda are kept so that, if there are a variety of jobs in the office, each one is separate and distinct in its entirety; finally, they are kept so that, as soon as a piece of work is completed, all memoranda in regard to it are immediately filed away and prevented from interfering with other work in the office.

The writer will describe the system as applied to building operations on a fixed profit basis, as in this way the principles involved will be understood, and concrete examples may be more easily obtained.

1.—Each piece of work is given a designating job number, and the estimate of original cost is entered in a monthly statement in a column headed "Original Allowance." In making up the estimate, the details of work, comprised under each account subdivision or number, are worked out in full, so that the cubic yards of excavation, and the incidental expenses thereof, are clearly stated.

In a column headed "Structural Steel," the number of tons of each of the various classes of steel, cast iron and other work, the price for the fabricated material, and the erection costs are stated, and so on down the list.

The sum of the statements in the column headed "Original Allowance" gives the total cost of the work, and these items are carried along in the monthly statements.

Any changes involving cost alteration are entered in a column headed "Additions." These additions appear in this column only for the month to which they refer, and in the following month are transferred to the "Original Allowance" column, leaving the "Additions" column free for the current month's changes. Mr. Hill.

The column headed "Payments" contains the summary of the disbursements under the various accounts to the date of the statement, and shows the total cost of the work to date. The sum of the payments plus the balance on hand in the bank (which is stated on blank lines at the bottom of the sheet) must equal the sum of money advanced or set aside for the conduct of the work.

All obligations incurred, either in the nature of sub-contracts, contracts for materials, and the like, are entered under the heading, "Contracts Made;" the column headed "To Complete" is only used occasionally, usually as the work approaches completion, for the guidance of officers or others who are not sufficiently familiar with all the details of the work to be able to supply the figures without assistance. It is rarely used more than three or four times on a job, but by being inserted in the monthly statement makes an additional form unnecessary.

2.—The time is kept in duplicate by using one or more time sheets as may be necessary, and making a carbon copy. The sheets are made up in pads, kept in an enameled leather case, and each week the originals are sent to the office.

The columns, "Total Hours," and "Amount," are usually filled in by the superintendent and checked at the office.

The pay-roll for each account number, as given in the monthly statement, is kept so that one man's name may occur several times on the pay-roll. The only disadvantage connected with this is that sometimes two pay envelopes are made out in the same name, the sum of the two being the correct amount earned.

In the writer's work, weekly pay-rolls amounting to $1 500 require two hours' time to check, draw the money, place it in the envelopes, and prove the accuracy of the distribution.

3.—Materials in general are provided for either in connection with sub-contracts or by agreement with supply houses. If delivery is to be made complete at one time, and the time is determined, one of the orders is issued; but if delivery is to be made piecemeal, or at different times, two or more orders are issued, and these are sub-divided so as to secure each delivery at the time when it will be needed. The order is made out in quadruplicate, the order blanks being made up in pads and in sets of four, so that, by the use of carbons, one writing suffices for the four.

The first or white copy is to be retained by the party receiving the order, and on the back of this the conditions of the order are printed.

Mr. Hill. The second, or pink copy, is a delivery receipt. It is sent with the order when delivery is made, is signed by the job superintendent, and, when the bill is rendered, is attached to the bill and affords a means of checking it.

The third, or blue copy, is sent to the job superintendent as a notice to him that the order has been placed. As soon as the order is delivered, he signs the blue copy and returns it to the main office, where it is filed temporarily and is an evidence of a debt which should be paid on the first of the following month.

The fourth, or yellow copy, is retained in the office for purposes of comparison with the other copies and as an evidence of an outstanding obligation.

This procedure is followed in all cases except for bricks, sand, broken stone, cement, and loads of rubbish, in which cases slips printed on stiff paper are issued, and are dated with an indelible pencil by the superintendent when issued. These slips are returned with the bill, and, after the bill is checked and audited, are destroyed.

The blue and yellow order slips are kept in the same file, and are usually arranged in groups, so as to be readily reached. When the pink order slip comes with the bill, the blue and the yellow copies which correspond are removed from the file and, after comparison, are crossed off, then the three slips are placed in a file for paid orders.

The order numbers are endorsed on the bill and, if necessary, are grouped under the account numbers so that the bill is separated into its component accounts.

4.—Small sub-contracts are treated the same as orders.

5.—In reference to payments, each job executed is conducted as an independent piece of work, the agreement with the owner providing that, from time to time, he shall furnish the funds necessary to conduct the work. The funds are deposited in the bank to a separate account. This is done because the only effective control that can be exerted on work is the control of the purse strings; that certifying to the owner that payments are due is very far from being the equivalent of a payment, and, finally, that where the builder's own capital is used for the conduct of the work, a charge would necessarily have to be made for such use, which would result in an increase in the cost.

The bank check used for this purpose is twice the width of an ordinary check. It is filled out so that the charge against the proper account number will appear on the face. The checks are carboned when written, so that an exact copy remains in the office. The check when issued is folded longitudinally, is endorsed in the customary way, passes through the bank as an ordinary check, and, although several thousand have been used with different banks, has met with no objection.

The check form is a typical pay-roll check. When a payment is

made, the check number is endorsed on the bill or voucher, and the bill or voucher is filed in a Shipman file in numerical order. Mr. Hill.

6.—In keeping the records, the writer uses a 9 by 13½-in. Shipman Common Sense Binder; heavy manilla sheets, with canvas tags bearing the account numbers, are used to separate the accounts, and regularly ruled ledger sheets are interposed between them for each account, as many sheets being used as are necessary. Additional sub-divisions are provided for recording the checks issued, called the "Cash Account," and for binding in the monthly statements. In small jobs, provision is made for binding in all contracts, sub-contracts, and additional orders received from the owner. On large jobs a separate binder is used.

The cash account sheets are regular ledger sheets, one-quarter of the upper left side of the page being used for the entry of money received. The remainder of the left side of the page is used for entering the checks, with date, number, name of account, and amount. The right side of the page is used for keeping a running balance. This serves two purposes, the balance on hand is always immediately evident, and the sum of the checks to date, obtained at the end of each month, must show a balance equal to that obtained by the partial steps, thereby proving the arithmetical operations. Each check is entered in detail in the detailed accounts, the first page usually being devoted to labor, and the succeeding pages to materials and small contracts. Entries are made in the detailed accounts showing obligations incurred, where contracts are made for specific amounts, and these are entered on the left half of the page. Where checks are drawn to pay bills, the entry on the left half refers to the bill, and the payment is entered by date and check number.

The sum of all the entries on the right side of all the pages must equal the total payments to date. These summations are usually made lightly with a soft pencil at the foot of the page, and are carried ahead for each account, so that the last page of the account shows the total amount paid thereon. The monthly summaries of the larger subdivisions of each account are made in ink, so that a simple subtraction or the addition of three or four sets of figures will always give the month's business, for that particular item. The bank book is written up each month, and, as no payments are made except by check, the bank balance should correspond with the balance shown in the accounts, which, through the bank, proves the accuracy of the total payments made, and this gives an amount which should be the total of all the detailed accounts. Comparing month by month, as given in the monthly statement, the progress of the work is evident.

The writer has made it a practice always to prepare his own pay-roll checks, and to visit the work at least weekly. Writing out the pay-roll checks serves to fix temporarily the cost of the preceding

Mr. Hill. week's work in the mind, and if a man is experienced in doing work, he can tell at once whether or not for that week's work he has received proper value for the wages disbursed. In the writer's experience, that is the best time to correct a foreman or a superintendent, because there is then likely to be little dispute as to the facts. This prevents the continuance of errors of organization, and shows where the ax should fall.

Generally, order slips and folded checks are of the same size, and all blanks are of conventional file size, so that any one of the filing system cabinets may be used. The cost of the work may be determined within a small fraction of 1% at any time by an examination of the file. Each file is independent for each job, and can be taken away for study, or the entering can be interrupted at any point without difficulty.

All receipts, cancelled checks, and paid bills are filed in a similar Shipman's file, so that on the completion of a job the entire records may be filed. The space required for a $250 000 building operation is about 9 by 14 by 12 in. By the use of the forms in this particular way, duplicates are obtained of orders, checks, pay-rolls, and monthly statements, carbons being an extremely important factor in saving time. On a $250 000 job the average monthly cost for all entering, bookkeeping, checking of pay-rolls, and the preparation of monthly statements was 16 hours at 35 cents, or $5.60.

As described in detail above, the system appears cumbersome; in practical working, it is simplicity itself, as is evident by the time and cost of keeping it up.

Mr. Lockwood. Willard D. Lockwood, M. Am. Soc. C. E.—Every engineer should be interested in the question of cost-keeping analysis and its publication, especially the latter, as it is the only way by which many engineers can get costs of certain classes of work with which they are unfamiliar.

The publication of costs will surely tend to draw contractors and engineers closer together as two equal parties to a contract, so that the contractor will not feel that he must hide his costs for fear the engineer may think he is making too much money.

Cost data which are to be published should be made by men who know all the unit prices paid by the contractor and the rates of wages, as well as all the overhead charges which do not show on a job, but which nevertheless go to make a total which materially changes the cost taken at the site.

On a great many works the cost keeping for the engineer is in charge of some young man who is not good for anything else, and, therefore, he is put on to take the force account. It soon becomes a bore to him, and he gets the force from the contractor's foreman or timekeeper. In the majority of cases, foremen and timekeepers feel

that the right thing to do is to pad the reports, so that the engineer will think they are losing rather than making money. Mr. Lockwood.

The same thing holds good with regard to unit prices of materials, for the clerks will give the engineer about ordinary retail prices, while, as a matter of fact, on large contracts the contractor buys at much lower prices than a dealer possibly can, because he buys in very much larger quantities.

To be of any real value, the cost data should give all or most of the conditions under which the work was done, and must be made either by the contractor's engineer, or the contractor and the engineer together. In no case should costs be published without a statement telling by whom they were kept and apportioned. The speaker once saw a clerk apportioning the cost from a power-house, and he gave a 10 by 12-in. hoisting engine four times as much as a 5-in. pump, although the pump ran 24 hours a day, and the hoisting engine certainly not more than 4 or 5 hours.

The speaker believes in the publication of costs, but he does not believe in the publication of wild guesses or haphazard records kept by irresponsible clerks or inspectors. With close relations established between engineers and contractors, however, the most valuable results can be produced.

Myron S. Falk, M. Am. Soc. C. E. (by letter).—The discussion makes evident the general agreement with the writer that the keeping of cost data is an absolutely necessary part of all construction work and that the compilers of those data are the ones to derive the greatest benefit. Mr. Falk.

Cost figures are to be used by the supervising engineer, as Colonel Black says, in case of dispute, to avoid a lawsuit or to enable the engineer to place himself on good ground for meeting one, and the keeping of these figures implies close supervision over work. As the writer has pointed out, the latter reason means the most to the man actually engaged in the construction; having made his contract, he must watch it day by day to see that all is going well; and compiling the daily costs is his only and best guide. Published cost data, showing past records, are of no benefit to a man at such a time. Mr. Lockwood's experience with the hoisting engine and pump, and Mr. Culgin's statements of the difficulties which the engineer meets in his attempt to obtain true costs of the work, show clearly the little dependence that can be placed on another man's cost figures.

Mr. Croissant describes the excellent system used by the Reclamation Service; curiously enough, it differs but little from that outlined by the writer, except as to the special and large work for which it was designed; the Reclamation Service evidently meets its pay-rolls monthly, whereas, in the system described by the writer, the men were paid either every week or every two weeks.

Mr. Falk. Mr. P. L. Reed's criticism of the clerical labor involved in the field is true, but as long as the services of a timekeeper are required, his duties can be made to cover this additional work, at no extra cost to his employer.

The writer is in thorough accord with Mr. Hill in his statement that good bookkeeping solves the problem of cost keeping.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1115

STEEL SHEETING AND SHEET-PILING.*

By L. R. Gifford, Assoc. M. Am. Soc. C. E.

With Discussion by Messrs. Charles W. Sherman, C. C. Conkling, Charles H. Higgins, Charles Evan Fowler, J. C. Meem, E. P. Goodrich, F. W. Skinner, R. B. Woodworth, and L. R. Gifford.

The subject of steel sheeting and sheet-piling, for some time past, has been receiving a great deal of attention from both engineers and contractors, and the many advantages of these materials, in comparison with the types of timber construction customarily used, is readily appreciated.

The general idea of metal piles is not new, but only within the last five or six years has any considerable progress been made in developing a form which was commercially practical and at the same time sufficiently economical to permit of its use except in special cases.

The earlier forms were of cast-iron, and a very interesting paper, by Mr. Michael A. Borthwick, published in 1836 and reprinted in "Ordinary Foundations," by Charles Evan Fowler, M. Am. Soc. C. E., gives drawings of a number of these forms, and describes their use at considerable length.

That cast-iron sheet-piling did not continue to be used to any great extent was doubtless due to its greater cost as compared with timber sheet-piling, as well as its general unsuitableness for work of this

* Presented at the meeting of March 17th, 1909.

character. It is rather remarkable, however, when it is considered that the difficulty of securing a satisfactory sheet-piling is one of the very troublesome problems with which the construction engineer has to deal, that other forms of metal sheet-piling were not devised, particularly in view of the apparent success which attended the use of the cast-iron piling. When cast-iron piling was first used, however, there was a much greater difference between the cost of metal and timber piling than at present, particularly in the United States, where timber was abundant.

At the present time there are a number of forms of steel piling on the market, and the many advantages which they possess have given them a deserved popularity, which has undoubtedly been augmented by the rapidly increasing cost of timber.

The writer has recently had occasion to study steel "sheeting" and "sheet-piling" quite carefully, and, in presenting briefly the result of these studies to the Society, does so in the hope that the subject may prove of sufficient importance to bring out a further discussion.

The best definitions of the terms "sheeting" and "sheet-piling" are to be found in the paper* by J. C. Meem, M. Am. Soc. C. E., entitled "The Bracing of Trenches and Tunnels, with Practical Formulas for Earth Pressures." Mr. Meem defines "sheeting" as that class of sheathing which is set in or driven coincidentally with the excavation; and "sheet-piling" as that class of sheathing which is driven ahead of the excavation, or beyond its final limits.

In what follows, an attempt will be made to determine the essentials of a satisfactory steel piling, and an analysis of some of the principal sections in use at the present time will be made.

The construction engineer's requirements for sheeting and sheet-piling are about as follows:

First. Strength, to resist earth or water pressure after the piling is in place, without an excessive amount of bracing;

Second. Stiffness, to enable it to be driven without buckling or springing under the blows of the driving hammer;

Third. Water-tightness, to prevent seepage.

On the other hand, the manufacturer will require a section which can be manufactured practically and economically, in order that the first cost shall not be excessive.

Transactions, Am. Soc. C. E. Vol. LX, p. 1.

The various forms of steel sheet-piling which are most used at the present time can be placed in three groups, as shown by the sections on Fig. 1. For convenient comparison, these sections are drawn to the same scale.

The first of the assumed requirements—that the piling must have lateral strength to support earth or water pressure—will now be considered. It will be seen that from this point of view the problem, stated generally, is to support a continuous and uniformly varying load over a flat surface, and the most convenient measure of the strength is the "section modulus," on the basis of 1 ft. width of the piling in place. This method involves the assumption that the sections when interlocked act as a unit. The diagram, Fig. 2, shows graphically how certain of the sections shown on Fig. 1 compare in this respect.

In constructing the diagram the vertical ordinates are the weight per square foot of the piling assembled, and the horizontal ordinates are the section moduli, expressed in cubic inches for a section 1 ft. in width. An inspection of the diagram will indicate the relative economy of the sections as regards the ratio of weight to strength.

The Lackawanna type would doubtless show approximately the same section modulus as the United States type, as the over-all dimensions of the flanges are about the same. The spring-lock type, as will be noted from an inspection of the drawings, depends on the material in the joints for its lateral strength, but, as the plate forming the body of the pile may be stiffened by standard rolled sections riveted thereto, it is difficult to include this type in the comparison.

The second requirement—that of stiffness to resist buckling while being driven—can be measured by the least radius of gyration of a single piece to be driven, and this is shown graphically on the diagram, Fig. 3. In this diagram the vertical ordinates, as in the previous diagram, represent the weight per square foot, while the horizontal ordinates are the least radii of gyration, in inches.

The third requirement—that of water-tightness—is met most economically by those sections which do not require auxiliary packing pieces, such as wood fillers at the joints, or caulking strips, to render them tight.

From the manufacturers' standpoint, the sections illustrated under Group 1 are desirable for the reason that they are composed of commercial structural shapes, which feature, however, is to a certain extent

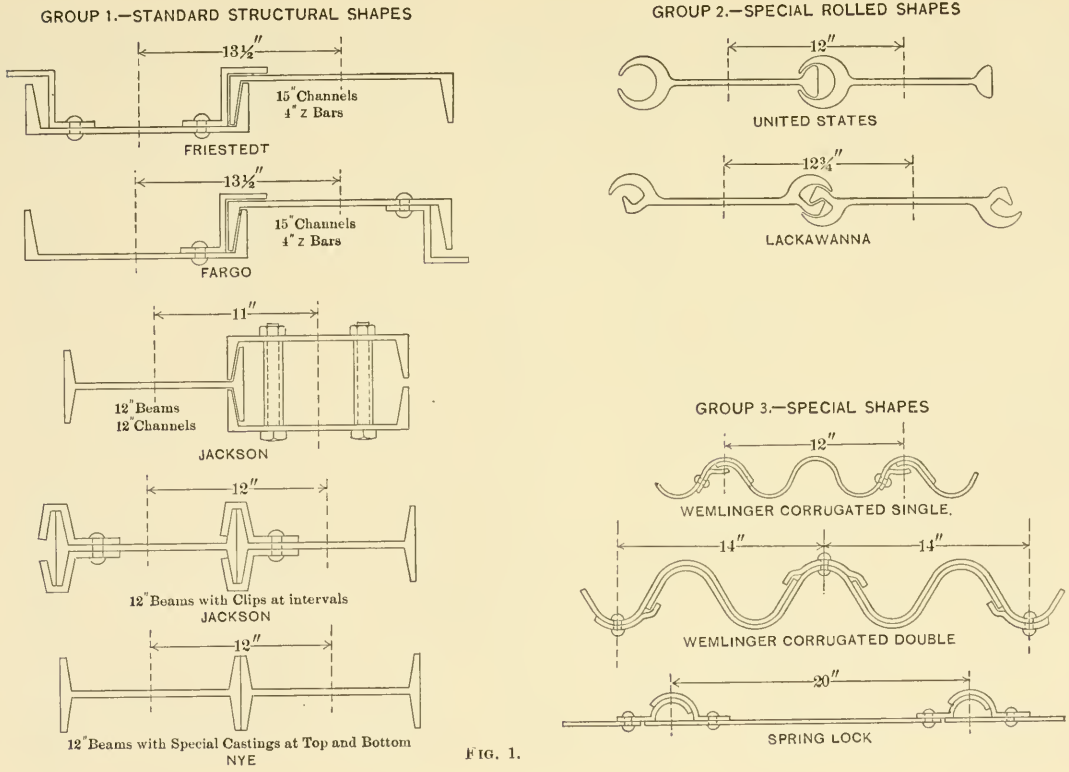

GROUP 1.—STANDARD STRUCTURAL SHAPES
13½″
15″ Channels
4″ z Bars
FRIESTEDT
13½″
15″ Channels
4″ z Bars
FARGO
11″
12″ Beams
12″ Channels
JACKSON
12″
12″ Beams with Clips at intervals
JACKSON
12″
12″ Beams with Special Castings at Top and Bottom
NYE
GROUP 2.—SPECIAL ROLLED SHAPES
12″
UNITED STATES
12¾″
LACKAWANNA
GROUP 3.—SPECIAL SHAPES
12″
WEMLINGER CORRUGATED SINGLE.
14″
14″
WEMLINGER CORRUGATED DOUBLE
20″
SPRING LOCK

FIG. 1.

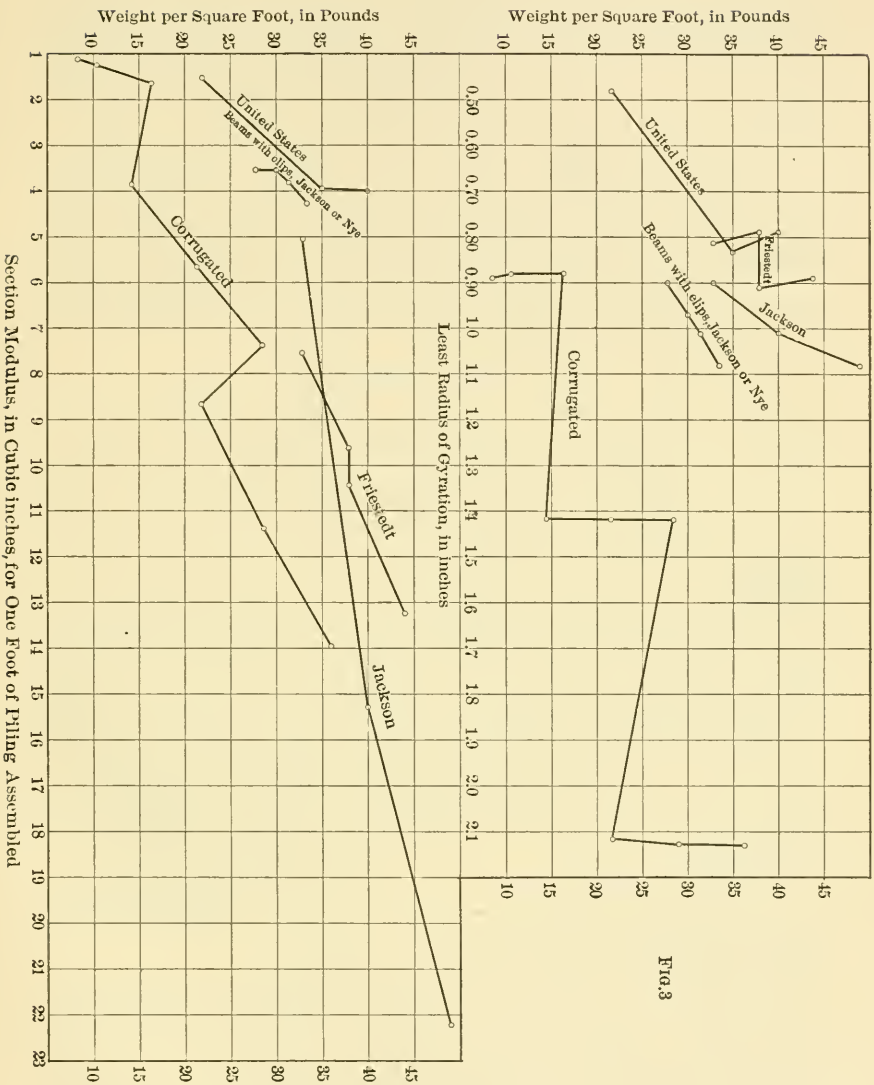


FIG. 2

FIG. 3

Section Modulus, in Cubic inches, for One Foot of Piling Assembled

offset by the fact that considerable shop work is necessary in order to rivet the various pieces together.

Special rolled shapes, Group 2, were designed in order to eliminate all shop work and permit of the sections being used as they come from the rolling mill, particular attention being paid to the interlocking feature.

The sections classified under Group 3 require considerable shop work, and are undoubtedly the more expensive of the various types on the basis of cost per pound of material, but this is offset by the fact that a much lighter and stronger section can be secured, which results, generally, in a lower cost per square foot of material in place, as compared with other types.

At the present time no satisfactory method is in general use for specifying the requirements of steel sheeting and sheet-piling. One method is to specify a minimum thickness; another is to specify a minimum weight per square foot after assembling. Neither of these methods is satisfactory, as both entirely overlook what, in the writer's opinion, are the prime essentials, viz., strength, stiffness, and water-tightness.

It is evident that the specification of a minimum thickness can be met by using a flat plate, but this, of course, would be entirely unsuitable, unless some means of properly stiffening the plate is provided, in order to enable it to be driven into place, as well as a proper method of joining the plates at the edges. The requirement of a minimum weight per foot can be met by increasing the weight at the joint and reducing the thickness of the metal between the joints, which is equally undesirable.

The writer considers that a proper and reasonable specification for steel sheeting and sheet-piling is essential and should be used by engineers whenever this material is to be used.

The problem of computing the strength required in sheeting and sheet-piling is a very difficult and complicated one, as is well illustrated by Mr. Meem's paper, previously referred to, and the discussion in connection therewith. It is very necessary, however, that any specifications should take this very important feature into consideration, and the following method, it is believed, will provide a satisfactory basis for specifying the minimum strength required.

The assumptions made are:

First. The pressure to be supported is hydrostatic;

Second. The sheeting or sheet-piling is in the condition of a simply supported beam, one support being the bracing at the top, and the other the ground at the bottom;

Third. The load is uniformly increasing from zero at the top to a maximum at the bottom.

Fourth. For permanent work, the allowable fiber stress should not exceed 16 000 lb. per sq. in., which provides a safety factor of 4; for temporary work, however, a fiber stress of 20 000 would not be excessive, and this provides for a safety factor of approximately 3.

Expressing the foregoing assumptions in a formula, we have:

$$S = \frac{4.01\ d^3}{16\,000} \text{ for permanent work;*}$$

$$S' = \frac{4.01\ d^3}{20\,000} \text{ for temporary construction;*}$$

when S and S' = section moduli in inches^3;

d = depth of water supported, in feet.

Proper bracing, of course, is essential, and the values obtained from these formulas are intended merely to provide for a maximum theoretical condition, to be used, as previously stated, as a basis for specifying the minimum strength required. For any special case, exact figures should be made, taking into account the spacing of the rangers and bracing to be used, the character of the soil, etc.

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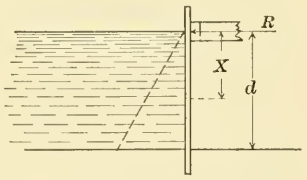
*X = distance from support to point of maximum bending,
d = span of beam, *i. e.*, length of piling between supports,
R = reaction,
M = bending moment at distance X,
S = section modulus of beam,
f = allowable fiber stress,
W = total load.



$$W = \frac{62.5\ d^2}{2}$$

$$R = \frac{62.5\ d^2}{6}$$

$$X = \frac{d\sqrt{3}}{3}$$

See "Treatise on the Resistance of Materials" Wood, p. 195.

$$M = \frac{62.5\ d^2}{6} \times \frac{d\sqrt{3}}{3} - \frac{62.5\ d^2}{2} \times \left(\frac{d\sqrt{3}}{3}\right)^3 \times \frac{1}{3d^2}$$

$$= 4.01\ d^3$$

$$M = f\,S = 4.01\ d^3$$

$$S = \frac{4.01\ d^3}{f}.$$

With this explanation of the paragraph relating to the strength, the writer offers the following specifications, which, it is believed, will provide steel sheeting or sheet-piling, without designating any particular form, which will meet any reasonable requirements.

Specifications.

Material.—All steel used shall be in accordance with the Specifications of the American Association of Steel Manufacturers for Structural Steel for Buildings, Revised to February 6th, 1903.

Unit Strains.—The allowable unit strains per square inch in bending on extreme fiber shall not exceed the following values:

For temporary work, 20 000 lb.

For permanent work, 16 000 lb.

Strength.—The section used shall have a section modulus per foot, when assembled in place, of not less than the following:

	Permanent.	Temporary.
Lengths of 10 ft. or less	0.25	0.20
" from 10 to 15 ft.	0.85	0.68
" " 15 " 20 "	2.00	1.61
" " 20 " 25 "	3.92	3.13
" " 25 " 30 "	6.77	5.42
" " 30 " 35 "	10.75	8.60

Stiffness.—Single pieces driven separately shall have a ratio of length in inches to least radius of gyration of not more than 250.

Water-Tightness.—The sections when assembled in place shall be water-tight at the joints, without the use of auxiliary packing or caulking pieces, unless such packing or caulking pieces are made part of and are assembled with the sections of the sheeting or sheet-piling before driving.

Driving.—Care shall be taken in driving to prevent battering of the heads of the piles, and, if necessary to prevent this, a tight fitting cap shall be used. Driving shall be done, preferably, by steam or compressed-air hammers.

Applications.

Steel sheet-piling of rolled sections was first used in the United States in 1902, when the Jackson type of beams and channels was utilized in the construction of a coffer-dam for the foundation of the Randolph Street Bridge, Chicago, Ill. Since that time the use of steel sheet-piling for coffer-dams of all kinds has become quite general.

The largest example is, without doubt, the coffer-dam now under construction for the United States Government at Buffalo, N. Y. This coffer-dam encloses an area 887 by 200 ft., in which is to be constructed a ship lock in Black Rock Harbor and Channel. Two lines of steel sheet-piling of the Lackawanna type are being used, driven 30 ft. apart and connected by cross-walls at intervals of 30 ft. The pockets thus formed are to be filled with clay, before the water is pumped out of the coffer-dam.

A very economical application of steel sheet-piling is its use in connection with dams or embankments, where it is frequently driven to form a core-wall designed to prevent seepage. The first suggestion of its use for this purpose which the writer has seen was that made by the late George S. Morison, Past-President, Am. Soc. C. E., in his paper entitled "The Panama Canal."* In this paper Mr. Morison proposed to use steel sheet-piling of rolled sections in connection with the "Bohio Dam."

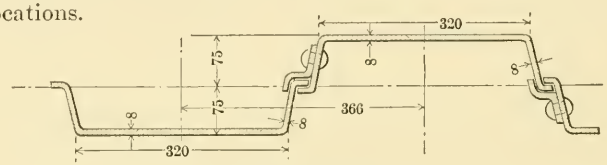
Probably the first actual application of steel sheet-piling for a core-wall was made by the Hackensack Water Company, near Hillsdale, N. J., the Friestedt type being used. A recent example is a dam at Scotland, Conn., for the Uncas Power Company, of Norwich, Conn. In this case an attempt was made to drive 6 by 8-in. yellow-pine sheet-piling of the ordinary tongued and grooved type fitted with malleable cast-iron chisel points. The soil was of a dense gravelly character, or, more properly, a hardpan, which the timber piling failed to penetrate, the piles brooming or splitting to such an extent as to be utterly worthless. Steel sheet-piling of the Wemlinger corrugated type, formed of $\frac{3}{16}$-in. and $\frac{1}{4}$-in. plates, was substituted and satisfactorily driven, although in some cases more than 4 000 blows of a steam hammer with a ram weighing 3 000 lb. were necessary in order to secure a penetration of 18 ft., due to the very compact character of the soil.

Another application of steel sheet-piling which is becoming more and more general is its use as shoring in the construction of building foundations, especially where the foundations must be carried below those of adjoining buildings or through soft or water-bearing soil. It is frequently possible by the use of steel sheet-piling to secure satisfactory foundations which would otherwise require the use of pneumatic caissons, which are very expensive.

* *Transactions*, Am. Soc. C. E., Vol. L, p. 177.

The construction of mine shafts is another application in which steel sheet-piling has been used successfully. However, probably the largest field for the adoption of steel sheet-piling is in trench work, and, while it has been used to some extent for this purpose, it is only recently that a type of steel sheeting has been developed which is economical in comparison with wood sheeting. This is due to the fact that it is now possible to secure a steel sheeting weighing 10 lb. or even less per sq. ft. which can be driven in widths of 12 in., and when it is considered that this sheeting, with proper care, may be used practically indefinitely, the saving over the timber is evident.

Recently, in the construction of a sewer at Summit, N. J., 100 lin. ft. of 10-ft. Wemlinger corrugated sheeting was used on 8 000 ft. of sewer in a trench varying in depth from 9 to 22 ft., that is to say, the same sheeting was driven and pulled at least 80 times, and at the completion of the job was still in good condition. This sheeting was made of 16-gauge material, weighing 5 lb. per sq. ft. in place. Sheeting of the same type is now being used for sewer and conduit trenches in Washington, D. C., Buffalo and Rochester, N. Y., and a number of other locations.



LARSSEN PILING
Dimensions in Millimeters

FIG. 4.

A use to which the lighter forms of steel sheet-piling are especially adapted is in connection with levees. Driven down through the center of these it would effectually cut off any seepage under them and absolutely prevent their being undermined by crawfish, muskrats, or other boring animals. The cost of the steel sheet-piling used in this manner would be largely made up in the saving which could be effected by the elimination of the muck ditches and the greatly reduced section of the levee itself made possible thereby.

Still another application is in the construction of docks and bulkheads, and, while it has never been used for this purpose in the United States, as far as the writer is aware, it has been done in Germany, at Hohentor Harbor, near Bremen, and in the port of

Bremen, where a considerable quantity of bulkhead work has been built of the Larssen type of rolled-steel piling, Fig. 4.

The Larssen type of steel sheet-piling was also used in the construction of the walls of two large ship-locks on the canal above Bremen, near Hamelingen.

In all these cases, the steel sheet-piling was driven along the bank, and longitudinal waling beams were afterward bolted to the piling, and the entire structure was secured near the top with anchor-rods fastened at one end through the waling beams and at the other to concrete slabs buried in the bank. The results are entirely satisfactory; the bulkheads present a very substantial appearance, and are much more economical in cost than concrete or masonry structures, while, at the same time, they are considerably more durable than timber bulkheads.

DISCUSSION

Mr. Sherman. CHARLES W. SHERMAN, M. AM. SOC. C. E. (by letter).—As an economical application of steel sheet-piling, the author mentions its use, in connection with dams or embankments, as a core to prevent seepage, and refers to two or three cases. While it is unquestionably true that, in original construction, such a method of making a tight core is both feasible and cheap in many cases, the writer has never been able to satisfy himself of the durability of such a core. Most embankments which serve to retain water are more or less saturated, and the steel sheet-piling, therefore, would be constantly in contact, throughout at least a part of its length, with moist earth, and rapid corrosion of the steel would seem inevitable under these circumstances. The rate of such corrosion would doubtless depend on the precise chemical composition of the steel and the character of the soil with which it was in contact. It hardly seems likely that, in ordinary cases, such a core would last longer than six or ten years, even though comparatively heavy steel sections were used.

Mr. Conkling. C. C. CONKLING, M. AM. SOC. C. E. (by letter).—The writer wishes to thank Mr. Gifford for bringing out some of the practical points in the design and use of steel sheet-piling. Having taken considerable interest in the subject, during the past two years, and having discussed it in general with many engineers and contractors throughout the country, he finds that, while they nearly all recognize the merits of steel sheet-piling and its great advance over the old methods of using wood, still there is a great deal of misunderstanding regarding the requisites of a steel sheet-pile, and of the work which it has to perform during and after its installation.

Observations, covering the plans and installations of this form of piling, under many varying conditions, lead the writer to agree with Mr. Gifford that the primary quality necessary in the steel sheet-pile is its ability to resist (as a beam) earth or water pressure, either as a beam supported at the ends, as a continuous beam supported at several points, or as a cantilever beam where no bracing is used. In the first two cases it should do this with the least possible amount of bracing. In the case where the pile acts as a cantilever beam, it resists these pressures without the assistance of cross-bracing, or mainly by its resistance against bending at or near its point of penetration, and the aid which it receives by being interlocked with the adjacent piles.

This applies where the piling is used without bracing, in the construction of low single walls or circular or rectangular pockets of shallow depth. After excavation, such pockets are wholly or partly filled with concrete, clay puddle, stone, gravel, etc., in order to form

units in foundations, large coffer-dams, dock walls, and other temporary or permanent constructions. Mr. Conkling.

Where the piling is used as a core-wall or curtain-wall in connection with earth embankments, such as levees, dams, etc., it assists against sliding, and, in the case of dock walls, against sliding and overturning; such conditions also produce a cantilever action. In the case of walls of various kinds, the pile may also assist in giving vertical support, as a bearing pile, by friction against the earth throughout the length of its penetration. In any of these latter cases the ultimate strength of the steel wall against horizontal or oblique pressure is largely dependent on the strength of the interlocked joint of the steel piling.

Such pressures brought upon an unbraced steel sheet-pile wall, especially in its upper portion above the point of penetration, tends to bow the wall and produce tensional and transverse stresses on the interlocked joints, making the strength of these joints one of the most important factors of the steel sheet-piling.

A theoretical steel sheet-pile would seem to be one in which the strength of the interlocked joint, under tensional or transverse stress, would be equal to the strength of the web of the pile under similar stress; taking into consideration, at the same time, the lightest possible weight which will give enough metal in the pile to produce sufficient stiffness to allow it to be driven to final position, and afterward to perform its duty as a beam.

At the present time, as far as the writer has investigated, there is no form of steel sheet-piling which exactly meets all these theoretical requirements.

To illustrate, in part: Take a pile having a web $\frac{1}{2}$ in. thick, allowing the ultimate strength of the steel in tension to be 60 000 lb. per sq. in. In a piece of piling 1 in. long, a web of this thickness would have a sectional area of $\frac{1}{2}$ sq. in., and an ultimate strength in tension of 30 000 lb. The joint of two such pieces, when interlocked, should then show an ultimate tensional strength, in direct pull, of 30 000 lb. per lin. in. of joint, thereby equaling the strength of the web.

In physical tests of a great many forms of piling, by pulling to destruction in an Olsen testing machine, the writer has noted joints showing $32\frac{1}{3}\%$ of the web strength, or 9 700 lb. per lin. in. of joint, as against $\frac{1}{2}$ sq. in. of web, this being noted as the nearest approach to the conditions mentioned. He has also noted interlocking joints where the same test showed only $4\frac{1}{2}\%$ of the web strength, which results indicate the great difference in the design and strength of some of the present forms of interlocking joints. These results might indicate that possibly, in some cases, the strength of the interlocking joint has been overlooked, or made secondary to supposed economy of metal, stiffness, etc.

Mr. Conkling. At first thought it would seem that the thickness of the metal in the web, over and above the amount required to equalize the strength of the interlocked joint, should be eliminated, thereby getting less weight and consequent lower cost. If this were done, in some cases, it would weaken the strength of the pile as a beam, and also conflict with the author's second requirement, viz., stiffness to enable the piling to be driven without buckling.

Most demands for steel sheet-piling, at present, include lengths running from 30 to 50 ft., though engineers are now taking up propositions calling for still greater lengths, viz., 50 to 65 ft. Such increased lengths can now be manufactured and driven, thus meeting the requirements for strength, if sufficient bracing is used, spaced at proper horizontal planes so as to give safe spans for the pile as a continuous beam, supported on the different sets of waling timbers.

Experience in driving shows that it is not necessary for a steel sheet-pile to have the rigidity required in a column as commonly used in structural work. While it must be stiff enough to resist buckling under the first blows of the hammer, a slight spring under the hammer, within elastic limits, during the first penetration, is not detrimental.

The length of the pile as a column, above the point of penetration, rapidly decreases with each blow of the hammer, and, by the time the point of the pile has reached the hard, underlying formations through which the penetration is slower, the columnar length of the pile above the ground has been shortened, so that the tendency to spring under the blow has ceased.

The entering and interlocking of the joint with that of the adjacent pile already driven tends at once to give stiffness, practically fixing the lower end. Where a slotted, cast-steel driving cap is used, being held in position by grooves against the leaders of the driver, the top of the pile is also practically fixed. These fixed conditions at the top and bottom of the piece, assist in preventing a tendency to spring under the blow.

To illustrate this point, the writer has seen a 45-ft. pile which had been bent in unloading and handling on the work so that it had a middle ordinate of about 20 in. This pile was entered and interlocked with the one previously driven, and, by careful manipulation of the pile-driver, was driven to refusal, the bend in the piece being entirely taken out as it went down by the stiffness of the members of the joint of the adjacent pile previously driven, the final result in this case being a straight pile with perfect alignment in the wall. The vertical and horizontal support which one pile receives by interlocking with another already driven is far greater than is generally supposed.

Steel sheet-piling is often used in formations, the upper portions of which are composed of clay, muck, peat, quicksand, or other soft material. A single piece of piling weighing from 1 600 to 2 000 lb.,

by its weight alone, will enter such material, in some cases, many feet. If it were not for the friction in the interlocking joint, the weight of the hammer resting on the pile, taken in connection with the weight of the pile itself, would be sufficient, in most cases of this kind, to produce the first 10% of penetration. Mr. Conkling.

On heavy work where the lengths of the pieces run above 50 ft., producing high tonnage and demanding economy of metal, it will pay to help out the pile in its first 50% of penetration by installing a series of movable wooden guides between the leaders of the driver, which latter will prevent the tendency to spring under the blow. It would seem economical, therefore, to require no more metal in the pile than is necessary to give it the required strength as a vertical beam after it is down, and just sufficient stiffness to get it down.

For these reasons the writer would place the requirement of stiffness as third instead of second, as given by Mr. Gifford, his third requirement, "Water-tightness," being given the second place.

Under this latter heading it would be possible to enter into a long discussion on the merits of the different types of interlocking joints, as affecting the final water-tight qualities of the wall. These different types naturally fall into two general classes, namely, rigid and flexible joints. Interlocking joints of the rigid type, when in normal position, have, in most cases, very small interior clearances between their members. The chance for the material which is displaced in driving to enter and seal the portions of the joints where the steel is not in actual contact is small as compared with joints of the flexible type.

These latter, with their large clearances or pockets, allow the displaced material to fill in these spaces and be compacted by the heads of adjacent joints when they are entered and driven, thus sealing the joints so that it is not necessary to use any artificial packing.

In driving a wall of steel sheet-piling, there are very few cases where stones in the form of large or small boulders, old logs, and other obstructions, are not struck. Sometimes these obstructions are sufficiently large, and, in the case of boulders, sufficiently hard, to prevent cutting through; especially is this condition to be met in deep work.

In such a case it is very desirable to be able, by the aid of the angularity of the flexible joint, to pass around the obstruction with the steel wall, driving to the same depth as previously done in the rear of the obstruction.

The flexible joint also allows the construction of circular or irregularly shaped pockets which are quite frequently desirable. By using joints of this type, these pockets can be built without the cost of bending the webs or additional fabrication.

In making closures in pockets, coffer-dams, or walls, the flexible joint allows distance to be gained or lost by the longitudinal displacement in the joint, or by deflecting slightly to the right or left.

Mr. Conkling.

These latter conditions also aid in bringing the piling back to vertical alignment, when, through meeting obstructions, or by careless driving, the top or bottom of the pile has been allowed to work ahead or back along the line of the wall. Where such inclination cannot be rectified, it may necessitate the manufacture of special tapered pieces in order to close the work.

The fixed joint, being somewhat rigid, reduces to some extent the first pressures on the waling timbers, where bracing is used in connection with the work. However, as soon as the excavation is carried to any appreciable depth, so that the pressures from the retained earth overcome the lateral stiffness of the joint, the work is thrown on the waling timbers, or, if no bracing is used, on the interlocked joints and the pile at or near the point of penetration.

It is probable that the perfect interlocking joint will finally be one which can be made flexible or rigid as desired, interlocking its members differently for each of these conditions.

Regarding the assumption that "the sections when interlocked act as a unit." By this the writer infers that the two parts of the joint are to be assumed as integral when interlocked. He does not believe this condition exists, except where the joints are grouted after the piles are driven. It is seldom that any form of steel sheet-piling is driven so that every piece making up the wall is in exact vertical alignment. Certain adjacent parts of the joints, therefore, may be in contact at any one point, and, further down in the same joint, similar points may be separated by a small space. Such latter spaces may be filled, at the time the pressure comes on the wall, with material displaced in driving, with silt carried in by water action, or the space may be left open. Also the small irregularities produced in fabrication and rolling tend to bring about similar conditions in the interlocked joints, all of which would prevent the two parts of the joint acting as a unit, at least in certain portions of the pile.

Therefore, if the section modulus is used as a relative comparison of the strength of the pile as a beam, it would seem better to use the section modulus of the full cross-section of one piece, or

$$\frac{\text{inertia of the section of one pile}}{\text{extreme fiber distance in same section}}.$$

The least radius of gyration, while the best comparison for theoretical stiffness as a column, should be considered in connection with the additional stiffness given to the piece by the interlock, density of material in which the pile is to be driven, and other conditions mentioned.

Economical water-tightness is certainly obtained, as explained by Mr. Gifford, by the non-requirement of auxiliary packing in the joints.

Mr. Conkling.

The methods generally used, to date, for specifications of steel sheet-piling, are not satisfactory, for the reasons which Mr. Gifford states.

It would seem safer to consider all pressures from saturated earth or quicksand as being hydrostatic. In cases where the wall is holding back such material, or dredged mud, it might also be better to consider the material as acting as a fluid, but having a weight of, say, 120 lb. per cu. ft., and to design the bracing to meet such conditions.

The writer would suggest that the working strength of the steel, in tension, might better be taken the same for temporary as for permanent work. Outside of deterioration of the steel in permanent work, which latter may not occur to any extent if the steel is protected, there would seem to be more liability for undeterminable pressures to be suddenly brought on the piling while in use in temporary constructions than in the more carefully planned and investigated permanent work.

Wood's formula, used by Mr. Gifford in his calculations of the strength of the pile as a beam, places the center of pressure nearer the center of the beam than is generally assumed by most authorities. This question, as well as similar ones presented in Mr. Meem's paper on the bracing of trenches and tunnels, is well worth the study and investigation of some of the expert mathematicians of the Society. There is no one line of work in which Civil Engineers are more often engaged than in building constructions to retain earth and water. If the long-used, old-time authorities are somewhat incorrect in their formulas, we cannot know it too soon for reasons of safety and economy.

With Mr. Gifford's permission, the writer would like to suggest the following additions to his specifications:

Under "Unit Strains" he would add:

"The working stress on the extreme fiber, under any condition, shall not exceed 16 000 lb. per sq. in."

He would also add:

"*Strength of Interlocking Joint.*—The ultimate strength, in tension, of the interlocked joint of the piling, for any given unit of length, shall be not less than 25% of the ultimate strength, in tension, of the web of the pile for the same unit of length, this joint strength to be determined by a series of physical tests in a machine."

Mr. Higgins.

CHARLES H. HIGGINS, ASSOC. M. AM. SOC. C. E. (by letter).—In this able and valuable paper, as in other discussions on the same subject, the writer has seen no reference to the value of a relatively high section modulus in preventing the bending inward of the sheet-piling below the surface of the mud, inside the dam, during excavation.

The writer may over-value this, but it is hard to believe that his experience with this difficulty is unique, for silt such as underlies the

Mr. Higgins. Lower Hudson, or some material similar to it, must frequently be met in the use of steel sheet-piling.

In the particular case the writer has in mind, the sheet-piling was driven to rock through some 30 or 40 ft. of silt, the water being 8 or 10 ft. deep.

For the benefit of those who are not familiar with the character of this silt at some little distance below the surface, it may be well to explain that this material, which is exposed at low tide, or is brought up by a dredge as soft mud, is so fine as to be held in suspension in water for a considerable time. In its natural condition, a few feet below the surface, it is a plastic solid, having a rather well-defined yield point and, when not exposed to water, standing readily with a vertical face of 8 or 10 ft., which would seem to measure what has been called its yield point; this increases inversely with the degree of saturation. A 4-in. cube, now before the writer, taken more than a year ago from the river bed, retains its corners and shows no signs of crumbling.

Sheet-piling, of one of the rolled sections mentioned by Mr. Gifford, was driven into this material, the water was pumped out, heavy bracing was placed, excavation was begun, and all went well. The bracing was placed immediately after removing about 6 ft. of silt, other bracing being placed every 3 ft. until a depth of some 15 ft. below the mud line, or from 20 to 25 ft. below the water line, was reached. Below this point difficulty was experienced in placing the braces, due to the sheet-piling bending inward below the line of excavation. This difficulty increased with the depth, and, although powerful hydraulic jacks were used, it became impossible to force the steel back to its original position; the area of the dam became more and more contracted, until at a depth of about 35 ft. below the water line, near the point where the rock was highest, the foot of the dam kicked in, and mud and water followed rapidly. The coffer-dam filled, and was only emptied and the excavation completed to rock by decking the entire structure and continuing the work under compressed air.

This sheet-piling had a radius of gyration of 0.8 and a section modulus of about 4.0 per ft. of width; it stood driving, even through old timber, behaved well with the bracing in place, and failed utterly through insufficient stiffness to withstand the unbalanced pressure in this plastic solid or cheese-like material below the line of excavation.

As far as the writer knows, this point has not yet been raised, although under certain conditions it would seem to be the determining feature in the choice of a steel sheet-piling, or even as to whether it might be advisable to use any form of an open coffer-dam. The writer calls attention to it in the hope of bringing forth some further information.

The huge coffer-dam of steel sheet-piling at Buffalo, mentioned as under construction, has recently been pumped out, and all interested in coffer-dams would be glad to learn what degree of success attended this operation. Mr. Higgins.

CHARLES EVAN FOWLER, M. AM. SOC. C. E. (by letter).—The use of metal sheet-piling is very limited in the Northwest, where the writer is located, and his opportunities for observing its use have been very infrequent. Mr. Fowler.

When the writer discovered the paper by Mr. Borthwick, published in 1836 in the *Minutes of Proceedings* of the Institution of Civil Engineers, he was very much surprised that metal sheet-piling had not been used more extensively in the past. It is especially remarkable that, upon the extended use of wrought iron and steel in place of cast iron, metal sheet-piles were not used more generally, but the reason, doubtless, has been that, until of late years, timber for the construction of coffer-dams has been remarkably easy to obtain and has been of low cost, as compared with wrought iron and steel.

In a great many cases it is also true that for such temporary construction timber is better adapted than steel in any form, mainly owing to the fact that it is necessary to make connections of bracing and staging at various points, and these connections can be made more easily with timber than with metal. In view of this, it is doubtful whether metal will ever supersede entirely the use of timber for sheet-piling.

A great point in favor of metal, as compared with timber, is the fact that, with the various dove-tailed patterns in use, the piling can be driven more closely and made more nearly water-tight than with any form of timber sheet-piling, even where a tongue and groove of dove-tailed form has been spiked to the timber, as this is apt to pull off in driving and leave bad leaks in the timber wall.

With reference to the pressures on sheet-piling, the author has evidently overlooked the fact that in a very great number of cases the pressure is not that due to the water, but to that from semi-liquid or very soft mud, and may easily run up to 50% more than that of water.

The specifications for metal sheet-piling proposed by the author are certainly satisfactory as to the class of steel to be used, as there is no need of having it manufactured under any special specifications. In the matter of unit stresses for steel, it would be safe to use a fiber stress of 24 000 lb. per sq. in. in the temporary work, and 20 000 lb. for permanent work. The ratio of length to least radius of gyration is certainly high enough, but this is a matter which can be determined very largely from experience obtained by actual use of the various forms.

Mr. Fowler. In the large majority of cases, the types shown in Group 1 would doubtless prove most satisfactory, owing to their greater sidewise stiffness and the better opportunities for making connections to them. There are, however, a great many cases, especially in shallow work, where the types shown in Groups 2 and 3 would be more satisfactory, on account of their lightness and less cost. Where the work is of any magnitude, it is always best to make a thorough investigation for each case, and adopt the form which is most satisfactory for the particular location.

Mr. Meem. J. C. MEEM, M. AM. SOC. C. E.—The speaker is a strong believer in interlocking steel sheet-piling, and, while he does not wish to appear as an advocate of any special type, he is glad to take this opportunity of speaking a word in favor of the more general use of this material.

Reinforced concrete piling is subject to the same fundamental disadvantages as those debited against wooden sheet-piling, in that it does not interlock and therefore may be forced apart by obstructions encountered in driving; and, further, that the corners cannot be made secure against an influx of sand or other material during excavating and pumping. Further, the speaker does not believe that the fear that harm may result from steel piling left in the ground is well founded. He bases this assumption on his belief that piling driven into the ground under water will not deteriorate after the outside heavy protective coating of rust has established itself, owing to the fact that there will be little or no further opportunity for oxidation, as long as the piling is not actually exposed to free water; and, further than this, if the steel should rust out entirely, the space occupied by the rust or oxidized iron ought to be far in excess of that of the steel itself, leaving no opportunity for voids to occur.

The speaker believes that the use of interlocking steel piling in long lengths is too well established as an engineering factor to make it necessary to point out its advantages; but he is not so sure that it is as well-known a fact that this material can be used to great advantage at times in very short lengths. He has had occasion to use very short steel piling in connection with the underpinning of buildings and existing subways along the line of construction of new work, and the following is a brief description of the methods used:

The piers of the building or subway to be underpinned were first shored on temporary beams in the ordinary way; 6 by 6-ft. pits were then excavated and box-sheeted with ordinary 2-in. planking down to the level of the water, after which 4 by 4-ft. frames of interlocking steel piling of the United States type, usually in 6-ft. lengths, that is, sufficiently long to reach about 2 ft. below the sub-grade of the adjacent excavation, were set up and driven to full depth; after which

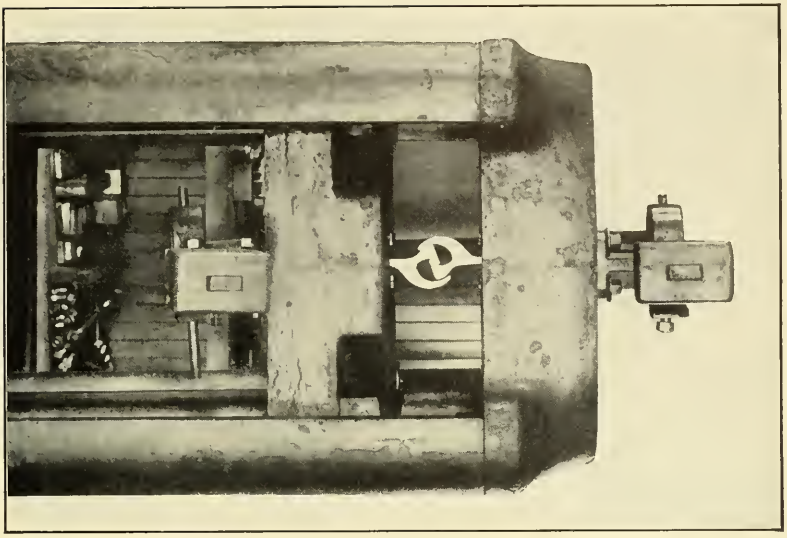


FIG. 1.—BEFORE THE LOAD WAS APPLIED.

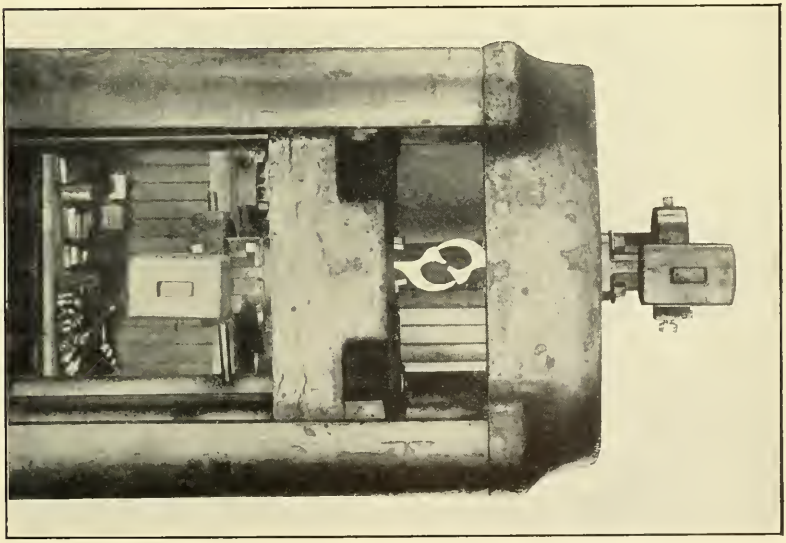


FIG. 2.—AFTER THE LOAD WAS APPLIED.

TENSION TEST OF LACKAWANNA STEEL SHEET-PILING.

the pits were mucked out to within a foot of their bottom and filled with concrete, the processes of excavation and concreting being carried on without unwatering the pile pit. Mr. Meem.

The result of this was that there was no influx of sand under the piling, as would have been the case had the pit been unwatered without having driven the piling to a much greater depth below excavation. As soon as the concrete in the pile pit had set sufficiently, the remainder of the pit was filled with concrete or bracing, and the work of underpinning was completed in the usual manner.

It is interesting to note that in many of these footings, which were nothing more than large square piles of from 1 to 2 ft. penetration, there was never any evidence of settlement, although they were at times subjected to a pressure of as much as 25 tons per sq. ft., with the adjacent material excavated to within at least 18 in. of the toe of the steel piling.

It is sometimes desired to use steel sheet-piling in very much longer lengths than can be handled conveniently owing to lack of head-room in building coffer-dams under streets and in congested places. In such instances it may be advisable to cut the piling into shorter lengths, driving the second and third sets as followers. Care should be taken, however, to break joints between the adjacent piles, and splice-plates should be tap-bolted into the ends of the abutting sections in order to keep one pile from crawling away from its follower while driving the adjacent member. Circular frames, 5 ft. in diameter, of steel piling in lengths of about 6 ft., have also been used to good advantage by the speaker as sumps for pumping out coffer-dams. Sumps of this shape can be driven continuously without the use of bracing, and are very effective. Piling of the United States type in 6-in. widths has been used most extensively by the speaker in these operations, but piling of the Lackawanna type or any flexible type should be equally effective. Great care should be taken in the selection of steel piling to secure the type best suited to the conditions.

It has come to the speaker's notice that a coffer-dam designed to have its piling act as a vertical cantilever resulted in developing stresses similar to those found in a suspended chain stressed horizontally. This condition, fortunately, had been foreseen by the engineer in charge for the contractor, and he selected for use a piling which gave a high strength of cross-pull in the interlock. In relation to this matter Table 1 gives some figures which show a wide variation in cross-pull at the interlock, as found in the Friestedt, the United States and other types. While the Friestedt is particularly effective as a beam, it has very little resistance to cross-pull in the interlock. The speaker is indebted to the Carnegie Steel Company for the figures in Table 1 relative to the Friestedt and United States types, and to the engineers of the Lackawanna Steel Company for the figures

Mr. Meem. relating to the Lackawanna type. It is only fair to say, however, that a built-up section such as suggested by Mr. Skinner should also give good results if specially designed for effective resistance against cross-pull.

TABLE 1.

Type of piling.	Section of piling.	Resistance to cross-pull per linear inch at interlock.
Friestedt steel sheet-piling	15-in. by 35-lb. channels, and 4-in. by ⅜-in. zees	1 500 lb. per lin. in.
	15-in. by 50-lb. channels, and 5 in. by ½-in. zees	2 250 " " " "
United States steel piling	12-in. by 40-lb.	12 000 " " " "
Lackawanna steel piling	12¾-in. by ½-in. web	9 970 " " " "
	12¾ in. by ⅜-in. web	9 970 " " " "

It would appear from the figures in Table 1 that very great advantage may be derived at times from designing coffer-dams so that the material in them will give thrust developing these stresses in the piling, thus saving a large amount of cross-bracing. These stresses can best be developed by driving the piling between supports with a "belly" or bow, making the versed sine of the latter as great as possible with reference to the horizontal distance.

Plate VIII shows the tests of the Lackawanna steel piling noted in Table 1, before and after pulling apart. The tests were made on a full-sized section 2 in. long.

Mr. Goodrich. E. P. GOODRICH, M. AM. SOC. C. E.—The speaker happens to have had some experience with almost all the different kinds of steel sheet-piling described in this paper, and has found that some types work better in some places than in others; sometimes one would be water-tight and sometimes it would not. Apparently, it is not so much a matter of the design of a tight sheet-piling as it is of the conditions met in its installation.

In Figs. 2 and 3 Mr. Gifford compares the section moduli and the radii of gyration of the different sheetings. He states that they are not strictly comparable because there exists a slight difference in price. With regard to this point, the speaker, for his own information, secured quotations on a certain quantity of material delivered in New York, and it was found that the curve for the corrugated sheeting should be raised perhaps about 2½% above that shown, while the United States and those which are rolled sections should in general have their curves lowered about the same amount. Thus the constituents are brought nearer to what may be called a median line.

The cost was computed in each case, and the speaker plotted on each diagram the corresponding position for a reinforced concrete

FIG. 1.—MOULDING REINFORCED CONCRETE PILES.

FIG. 2.—LINE OF REINFORCED CONCRETE PILES IN PLACE.

Mr. Goodrich

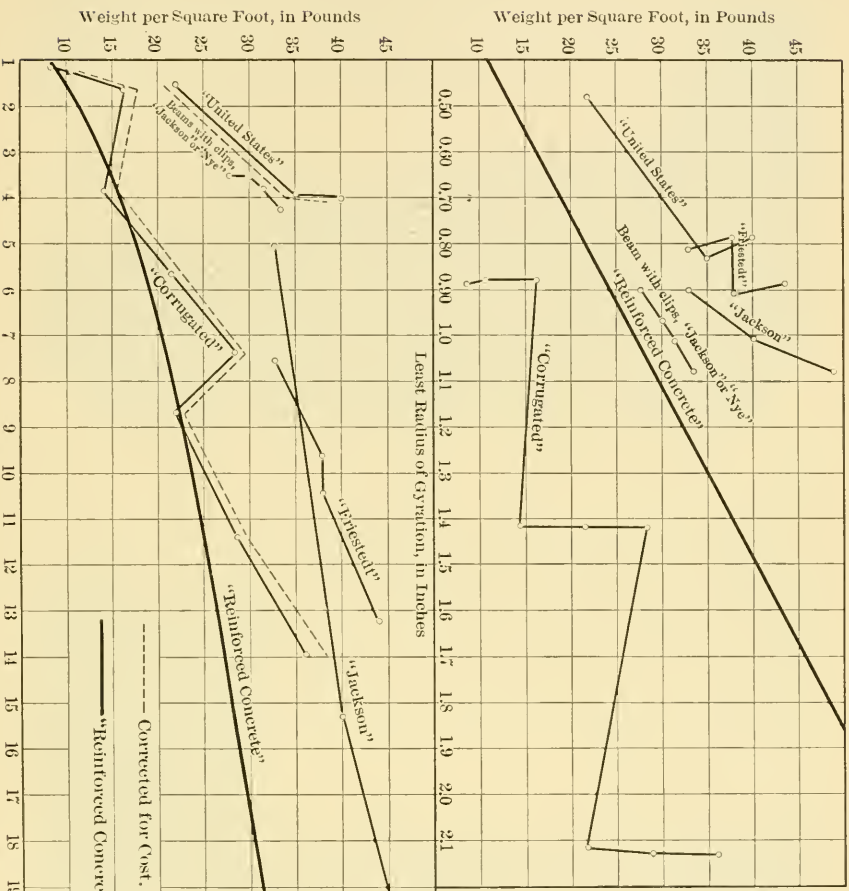


Fig. 5

Fig. 6

Mr. Goodrich.

piling which would be equivalent in strength and in stiffness, according to the data used, with the steel sheeting. In making this computation, 1% of reinforcement was calculated at 4 cents per lb., and the concrete at 30 cents per cu. ft. In each case the cost of driving is to be added to the cost shown. The results are shown in Figs. 5 and 6, the heavy line showing the position of the reinforced concrete sheet-piling.

In the case of the radius of gyration, the comparison is not strictly correct, because long before the stiffness of reinforced concrete piling is tested at all, it is likely to be shattered by the heavy driving which would be required. In making the comparison shown by the diagrams, Figs. 5 and 6, the ratio of the moduli of elasticity has been taken into account. If the ratio of the moduli is ignored in computing the radius of gyration, the heavy line would be moved considerably to the right, which would make concrete far superior even to corrugated piling.

In the footnote on page 447 the author has computed simply the upper section of a line of sheeting, which ordinarily is braced at more than one point. If there is a wale at the top and a wale at the bottom, perhaps the author's assumption would be correct, but ordinarily there are more than two waling piers, so that the strengths which he has computed should be increased to a certain extent. To make that comparison, the different positions of the points of maximum moment for different depths have been computed, each distance between wales being taken at 10 ft., with the following results: The distance from the heaviest reaction to the point of maximum moment in simply supported beams with loads similar to those produced by lateral earth pressures, between depths d and d—10 ft. below the surface is as follows:

$d =$	10	20	30	40	50
$\alpha =$	4.23	4.73	4.84	4.88	4.91

Of course, 5 ft. would be the center, and is the point of maximum moment which would correspond to a uniform load. The close approach to this figure at considerable depths shows that in piling 30 ft. long, the load might as well be considered as uniformly distributed, as far as the moment is concerned. Even the accuracy which has been secured in this case may be entirely lost because of the simple buckling of one of the struts against the wale, rendering impossible the assumption of rigid supports, on which the moments are calculated, so that in any case the strengths should be made ample.

The author mentions the use of steel for levee work and for core-walls, to prevent seepage, and also for the construction of docks and bulkheads. It seems to the speaker that the use of steel sheet-piling in permanent work is open to question, because the effect of the earth

FIG. 1.—INSIDE VIEW OF SHORT LENGTH OF REINFORCED CONCRETE PILING.

FIG. 2.—BACK VIEW OF LENGTH OF REINFORCED CONCRETE PILING.

with regard to rusting steel or iron in the ground is well known. It is likely that the rusting out of sheeting in such locations would destroy its value after a few years. For that reason, it is thought that, in such locations, reinforced concrete sheeting properly made would be superior to steel sheeting. Plates IX and X show some concrete piling used in connection with the Baltimore dock improvement work. In it the side construction consists of reinforced concrete sheet-piling with horizontal, overhanging, concrete girders. Mr. Goodrich.

The sea wall is built upon the top of the combination, which is tied back by reinforced concrete struts. At various intervals along the dock front, steel caissons filled with concrete were installed in front of the piling to support the wall temporarily. After a while, of course, the steel on the front caissons or cylinders will probably be rusted out, but the concrete core will be left to bear the load. Plates IX and X show some of this work in progress. Fig. 1, Plate IX, shows the moulding of the piles. The material was handled by derrick, and, after hardening, the piles were loaded on a barge and floated to the drivers at the site of the work. Fig. 2, Plate IX, shows a line of piles in place, together with the forms and reinforcement for the front horizontal girder and for some of the concrete-covered anchor members. Fig. 1, Plate X, is an inside view of a short length of the piling with a tie member and the temporary end of a section of wall. Wires were moulded into the ends of the piles by which to support the girder forms. Fig. 2, Plate X, shows a longer stretch of piling, viewed from the back, together with two stretches of wall and some anchor members. The diagonal positions of the latter are evident, and one of the anchor piers is visible.

The speaker was connected with this worl as a Consulting Engineer with the Sub-Contractor doing the concrete work, the Raymond Concrete Pile Company.

Frank W. Skinner, M. Am. Soc. C. E.—The Society is indebted to Mr. Gifford for this very valuable and instructive presentation and analysis of the typical varieties of steel sheet-piling, embracing those which may be considered as notably characteristic of present practice; and Mr. Goodrich has given authoritative and valuable information on reinforced concrete sheet-piling, which is now in its infancy, but may hereafter become a very important factor in construction. Mr. Skinner.

Little can be said except in commendation of the paper, but there are some points on which it may be proper to offer a few remarks. Before considering the subject attention should be called to the most admirable distinction between sheeting and sheet-piling made by Mr. Meem; all would do well to follow it.*

In addition to the piles illustrated by the author, there are two other

* *Transactions*, Am. Soc. C. E., Vol. LX, p. 1.

Mr. Skinner. classes which are deserving of recognition, either for some special value or for some quality exactly the opposite, and sketches of some of them are submitted. These, no doubt, are familiar to many, but their presentation will serve more perfectly to complete the cycle.

The Jones and Laughlin type has a special section somewhat resembling an I-beam with curved flanges. These engage the flanges of alternate I-beams of normal section; thus there are two distinct bars to be rolled and driven. The advantages are that the I-beams are used exactly as commercially obtained, the sheeting has very great stiffness transversely, and it is stated that the piles are driven very easily. Doubtless, this type will find considerable application where conditions require a heavy pile, one without a particularly water-tight joint, and in which ready driving is of importance.

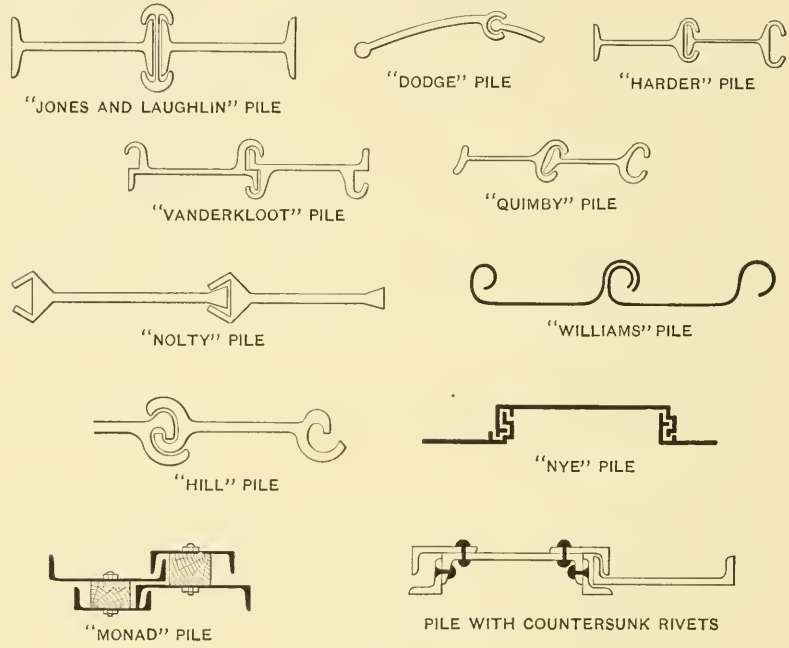


FIG. 7.

The author illustrates only two of many patterns of the interlocking I-beam type, viz., the United States, and the Lackawanna piles. There are also in this class the Dodge, Harder, Vanderkloot, Quimby, Nolty, and Hill patterns, some of which are symmetrical, and some distorted, but all are calculated to have curved, interlocking, heavy, transverse flanges, completed in the rolls. It is believed that these types have not been used as much as the United States or the Lackawanna types.

Mr. Skinner.

The United States pile has had a great and well-deserved popularity; it is of moderate weight and stiffness, is easily driven and pulled, and has an attractive, open joint, allowing considerable flexibility. It is very suitable for clay and some other heavy, dense soils, but is not water-tight without caulking of some kind.

The Lackawanna pile was only recently put on the market, and has many of the same or similar good qualities. It is claimed to develop unusually great tensile strength in the joint, and to have given excellent satisfaction in a very large Government job in which it was selected by competitive test with a number of other types. It has a strong section, well adapted to stand abuse, and has a record of being pulled and re-driven twenty times. The ½-in. section weighs 40 lb. per sq. ft. of web.

The Williams pile is noticeable for its fantastic appearance. The speaker is not aware that it has ever been actually used, although it has been patented. The lock is made with a weak, clumsy, double scroll—evidently, a good thing to avoid.

The Nye pile is in the same category. Presumably it is a cast-iron pile, with an intricate section, impracticable to roll or rivet.

The Monad pile has been used with fair success, and is a combination of timbers and channels. The timbers are bolted to the channels, and make an interlocking pile. It was used to some extent in part of the work on Brooklyn Dry Dock No. 4. The advantage claimed was that it was made from commercial shapes, without any shop work; that it gave, theoretically, 100% salvage; and that it required no fabrication or preparation except to be bolted together in the field as used. Of course, the joint was not water-tight, and there was excessive displacement and friction in driving.

Among the points which the author emphasizes as the requisites for theoretically perfect steel sheet-piling are the stiffness and the moment of resistance. It is quite right that sheeting and sheet-piles should possess such qualities, but the speaker is strongly of the opinion that they need not, and, indeed, preferably should not, be inherent in the pile unit. In other words, it is quite possible to provide these qualities more economically, exactly, and satisfactorily, by adding them to the piles as they are driven, or after they are driven, and to proportion them to a minimum standard unit. This is one of the distinctive features between rolled and built pile units.

The rolled pile units have many advantages. Perhaps the foremost is the great advantage to the rolling mills! Most of these piles have heavy sections, and as the rolling mills make a large tonnage profit on all heavy shapes, and can afford to neglect fabrication profits, they have certainly every reason to favor a heavy section. Rolled pile units are solid, durable, simple, easily and quickly made, and easily driven. One of their disadvantages, outside of their weight, is that they are

Mr. Skinner. absolutely inelastic. There can be no variation except with different sets of rolls and by changing slightly the thickness of the web. Another objection is the difficulty or impossibility of securing a really water-tight joint with rolled sections. Still another objection is that they never present a smooth, flat, wall surface; it is always diversified with ribs and grooves.

In many places the rolled types suffice, because it is often quite unnecessary that the joints should be water-tight, and because sometimes, under favorable conditions, joints not water-tight become silted up by the inflow of sand and mud after the piles are sunk; in clear water, however, that result is not obtained, and a water-tight joint is a desideratum.

Both the water-tight joint and the variation of section can be, and have been, obtained in built-up or riveted piles. Of these there are several types. Some of their advantages are that it is possible to secure an absolutely water-tight joint from the outset; that they may be easily proportioned for any required service; that some of them are adaptable to a very wide range of cross-section and special details; that a very great economy of weight can be secured; that they can be suited to all kinds of angles and dimensions; and that they afford a perfectly flat, smooth, and continuous wall surface.

There are disadvantages, too, in the delay for fabrication, and in the additional cost of shop work, outside of the cost of material. Generally, when built up of standard shapes, there is excessive weight, often without corresponding effectiveness of section. Some of them involve very objectionable countersunk rivets, which are a source of weakness and expense. The dimensions and sections are limited almost as much as in the simple rolled sections, and the joints are no tighter. These difficulties can be eliminated by using a simple plate web provided with a universal, independent, and efficient joint. A great disadvantage, in most cases, has ordinarily been experienced in driving, because if the piles were made heavy enough to stand hard driving, the extra weight required to stiffen the web might equal that of the rolled pile, which, added to the shop cost, would immediately put them out of consideration on account of the excessive cost; and if they were made thin enough to give them economy of cost, they would be too thin to drive, except under very favorable circumstances. Both of these objections have been overcome, and in one pile with which the speaker is most familiar, they have entirely disappeared.

Returning to the two points, the stiffness and the strength of the pile, the speaker would like to justify his assertion that these attributes may be added to the pile, and often with much advantage. Although they are necessary, one cannot determine in advance what they should be for different classes of work. It may be known, in a given instance, that there will be a certain pressure against the piles, and the bending

moment can be calculated exactly and thus the resistance which must be given to them. Then if a smooth, continuous, water-tight surface, made up of very light standard units, can be installed satisfactorily, it may be braced and stiffened arbitrarily with detachable reinforcement in order to meet requirements as they arise; and, after the work is finished, the pile units and the reinforcement may be recovered and separated for future use. Mr. Skinner.

It may be known in a general way that the driving will be very hard or very easy—or it may be between the two—and, if the piles are for permanent service, they may have suitable reinforcement fabricated with them; but every job varies, and one pile cannot be made to meet all requirements.

Heretofore, and still almost entirely, it has been the custom for one manufacturer to make one, or possibly two, lines of piles, and then try to introduce them everywhere. They are his goods. He recommends them everywhere, "for a wedding or a funeral," and one has to take them or use some other type; but no manufacturer can introduce much variation.

Now, a steel pile should be designed to "make the punishment fit the crime" in every instance, and should be just as well adapted to the service for which it is intended as any steel structure, a bridge, a truss, or a building. That can be done if its elements are variable, and they can be made variable only by the application of a universal, interchangeable joint to such a cross-section, web, or body, as may be chosen.

The remainder of these remarks will apply equally well to any type of sheet-piling in which a detachable joint or an independent joint, fulfilling the requisites of economy, stiffness, tightness, and simplicity, can be used, whether it be the one adopted herein in discussing the subject or any other. The speaker will illustrate with the spring-lock joint, because he is most familiar with it.

Theoretically, the speaker maintains that a steel sheet-pile, in its simplest terms, is only a diaphragm—water-tight, if necessary—sunk to the proper depth and in the proper position, and to that the stiffness and other qualities are simply incidental, and can be arranged as required. Therefore the greatest economy and efficiency is secured by the diaphragm which is most perfect and most cheaply installed, that is, when the total cost is least, providing any additional requirements do not make that cost greater than that involved by some other type.

That, of course, resolves itself then to the simplest thin sheet, fitted with some sort of connecting and interlocking joints. Consider first a sheet of any arbitrary thickness and width, and of such length as may be demanded by the conditions. Such a sheet has curved joint-bars, nearly but not quite the same, riveted on each longitudinal side.

Mr. Skinner. Now it is perfectly plain that these joint-bars are as simple, and as easily manufactured and fabricated as an ordinary angle; they can be applied, not only to a sheet of any dimensions, but to a channel or an angle, or to almost any compound section that may be made. The joint is interlocked by taking the male bar of one sheet and engaging it with the female bar of another sheet.

TYPES OF "SPRING LOCK" JOINTS.

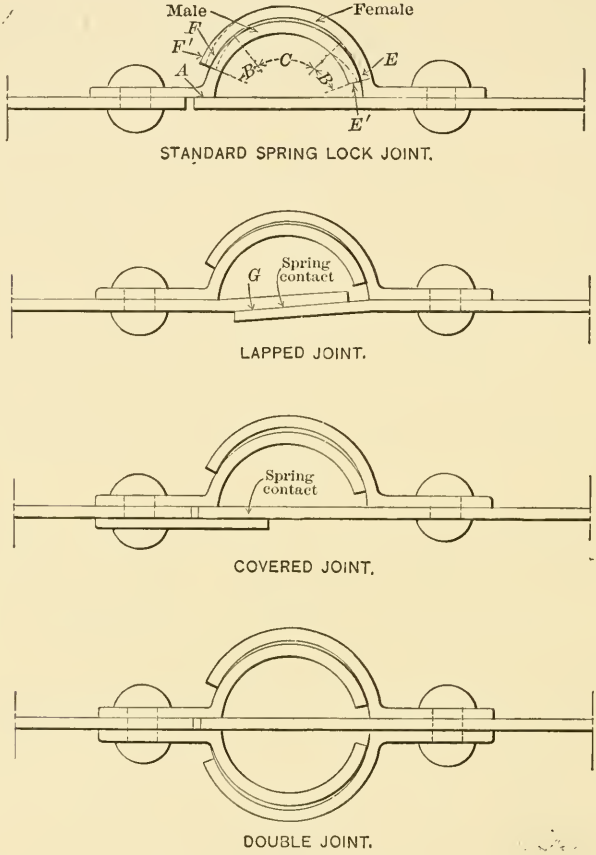
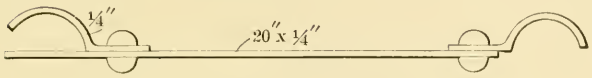


FIG. 8.

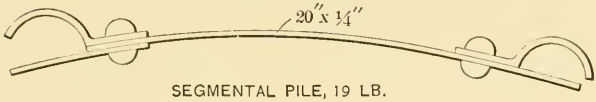
As fabricated, the flanges of the male and female bars take the positions E and F, as indicated by the dotted lines in Fig. 8, but when forced into engagement, they spring about $\frac{1}{64}$ in. into the positions shown by the full lines, E' and F', with cylindrical bearings at B and B, and a clearance of about $\frac{1}{32}$ in. at C, which diminishes friction in driving. The elastic resilience of the metal holds the pieces in firm

Mr. Skinner.

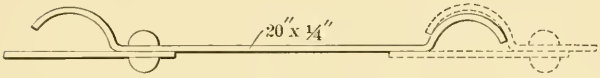
TYPES OF "SPRING LOCK" PILE UNITS.



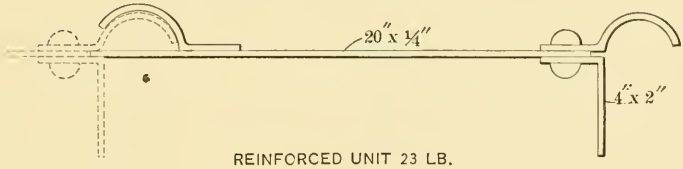
SIMPLE PILE, STANDARD UNIT, 17¼ LB. PER SQ. FT.



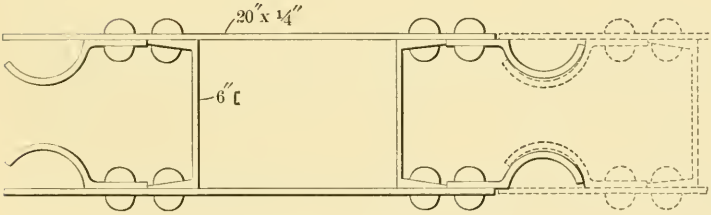
SEGMENTAL PILE, 19 LB.



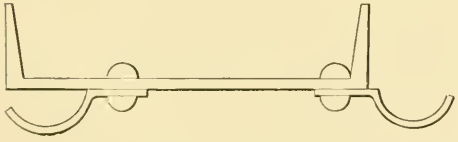
SINGLE-RIVETED UNIT 15 LB.



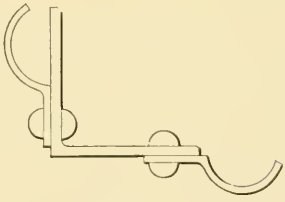
REINFORCED UNIT 23 LB.



HOLLOW RECTANGULAR UNIT 45 LB.



CHANNEL UNIT



CORNER UNIT

FIG. 9.

Mr. Skinner. contact at three places, *B*, *B*, and *A*, and secures an elastic, live, water-tight joint, with enough spring to maintain contact when driven, pulled, and re-driven, and at the same time yield a little when necessary and allow for imperfections and irregularities of manufacture and fabrication. The joint can be made double by the addition of a cover-plate on the flat side, or it can be varied by extending both web plates to overlap when they, being originally in the same plane, are slightly displaced in order to clear while driving, and thus provide a third spring contact, *G*. If exceptionally great transverse tensile strength and extraordinary reassurance against leakage are required, they can easily be secured, and a joint with most exact and rigid alignment, combined with elasticity and adjustability, and very efficient disposition of metal, stiffness, and lightness, is attained by making the double joint, with six lines of contact, which is still flexible enough to adapt itself to ordinary imperfections and irregularities. In all these different joints the tightness can be easily adjusted and the clearance varied materially in the field simply by swedging in the outer edge of either the male or female joint-bar with a sledge hammer.

Piles of moderate length, made with 20 by $\frac{1}{4}$-in. web plates, and $\frac{1}{4}$-in. joint-bars, and weighing only about 17 lb. per sq. ft., may be driven in soft ground by ordinary methods. For long lengths and hard driving, the same pile unit may be used, if great permanent stiffness is not required in the finished sheeting, by reinforcing the pile temporarily with parallel channels, of full length, clamped to opposite sides of the web plate, making a very heavy, solid, I-shaped cross-section. Both the upper and lower ends of the channels may be reinforced, and may project a little beyond the ends of the pile web, thus serving, not only to stiffen it and receive the impact of driving, but also to act as a pilot, protecting it from injury from obstructions and from battering by the pile-driver hammer. The compound section is very easily driven, and then the two reinforcing channels can be immediately pulled and used over and over again, thus serving for the installation of the sheet-pile, which can be designed with very little stiffness.

If additional stiffness is required, after the channels are removed and the sheet-piles are in service, it can be secured easily, economically, and efficiently by facing the inner surface of the sheet-pile wall with horizontal boards, placed successively below each other as the excavation is made. Transverse bearing pieces of convenient lengths are set on the boards and receive the rangers or the ends of tranverse cross-braces, exactly as used for any sheeting of trench or pit work. Bracing of any type or dimensions can thus be adopted, and can be proportioned to give any required strength without increasing the cost of the sheet-piles above the minimum required to secure a water-tight diaphragm.

When it is desirable that the sheet-piles should possess considerable permanent independent stiffness, it can be added to the regular thin-webbed sheets by reinforcing them with angles, channels, etc., as required. A single angle, riveted opposite the male joint bar, which usually should be driven in advance, only increases the weight a very small amount, and gives great stiffness. Obviously, the number, arrangement, and dimensions of the angles can be varied in exact accordance with the variation of stress or other requirements, so that the pile may be proportioned accurately for its specific service without involving any waste material. In the case of a very long pile under hydrostatic pressure, the stiffness may be made very much greater at the lower than at the upper end, a result not attainable except in a riveted pile. Mr. Skinner.

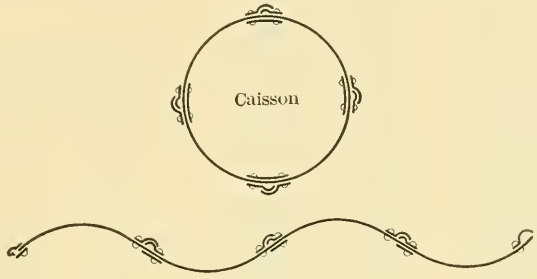


FIG. 10.

Riveted piles with flat web plates are especially suitable for circular caissons, which, with covered joints as shown in Fig. 10, are very rigid, developing true cylinder conditions, and, for moderate dimensions, sufficing to resist uniform external pressures without any interior bracing.

If the joint-bars are riveted on opposite sides of alternate units, they assemble in large corrugations, which, with their tight interlock, produce substantially a series of alternately reversed, counterbalanced arches of enormous strength against transverse pressure, and with very little increase in either cost of fabrication, installation, or weight of metal, over the plain, thin, flat webs. In this case, however, it is necessary that the sheet-pile wall should have a greater thickness, and the uniform, flat, plane surface of the inner side of the wall is sacrificed to the additional strength, a feature which is often of no importance.

For extremely hard driving, or for great lengths or for exceptional strength, a hollow, rectangular pile is made with two plates, two channels, and four joint-bars which, with a weight of only 45 lb. per sq. ft., is many times stronger and tighter than any other possible form of interlocking sheet-pile. The piles may be provided with a

Mr. Skinner. solid point or shoe, and their large interior cavity permits very efficient use of a water jet for ordinary sinking in sand or to wash down boulders or other obstructions. The duplicate joints insure great strength and tightness in the interlock.

The fabrication of the joint-bars separately from the web or body makes them available for combination with webs of any dimensions, and enables any special section to be fabricated at short notice from standard commercial structural materials easily maintained constantly

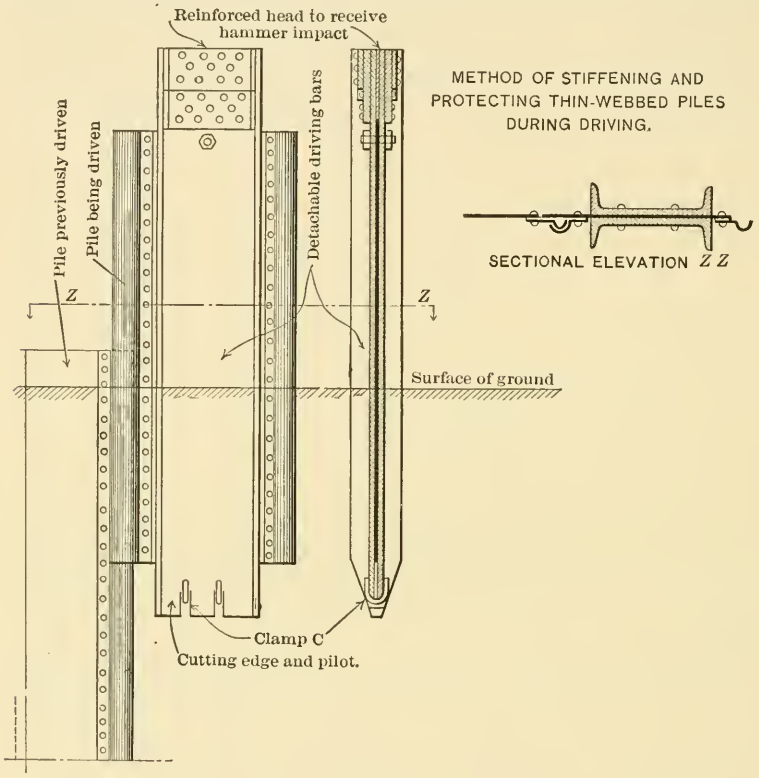


FIG. 11.

in stock. The maximum ultimate economy and excellence, however, are attained by rolling the joint grooves in the web plate and then riveting only a single flat cover-plate on each pile unit.

All these different attributes might be enlarged upon, but the speaker desires to give some attention to another point in sheet-pile construction, namely, the disadvantage of having any joints at all.

As far as the speaker is aware—and he has had occasion to investigate and design a good deal within the last few years—about one-half

the cost (and in some cases more) of interlocking sheet-piles is directly due to the joints; that is, the diaphragm, web, or body of the pile, costs only about half as much as the complete pile. Mr. Skinner.

Of course, the joints in most cases contribute largely to, and often are the entire source of, stiffness and lateral strength in the pile, but the material is not usually disposed efficiently or economically; therefore, if the joints are eliminated, or very much reduced, the economy of the pile is greatly increased. There are then fewer points for leakage, and the surface is more uniform.

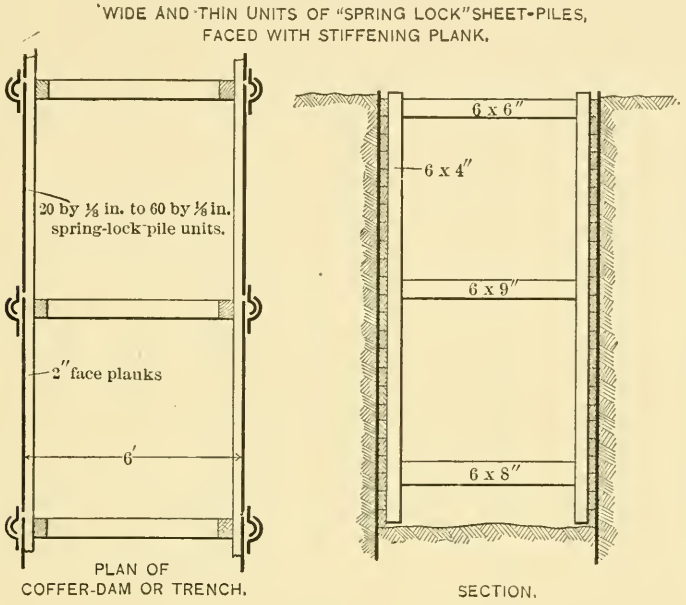


FIG. 12.

It is entirely practicable to manufacture and install successfully riveted-joint piles, having any width and any thinness of web, which can be fabricated, transported, and handled. That is, within perfectly reasonable and ordinary limits, a sheeting for a trench, coffer-dam, or other structure, might reasonably be made with webs ⅛ or ¼ in. thick, and 72, 84, or 96 in. wide, fitted with water-tight joints on the edges and interlocked, and forming a diaphragm.

That result is accomplished in a manner which the speaker regrets he is not at liberty to explain in detail, but it is done by a very simple and practicable device, corresponding very closely to the use of pilot piles.

It is accomplished very successfully, and by a simple method of displacement. A cavity, in any kind of ground adapted to pile driving,

Mr. Skinner. is produced of any width up to 12, 18, or possibly 20 in., of any required depth, within reasonable limits, perhaps from 20 to 40 ft., according to conditions, and of any length. It is made sectional, and gives an absolutely unencumbered trench or recess in the ground which may be no more than 3 or 4 in. wide, in which diaphragms of any pattern—a sheet of plate glass if necessary—can be inserted, the joints made, and the earth allowed to resume its position, closing up on it and forming its own back-fill.

This method, as suggested by Mr. Goodrich, has the advantage of providing against the deterioration of the metal structure. Suppose the trench which is to receive the diaphragm is made 12 in. wide, instead of 3 in., which would be necessary to accommodate the sheets and their joints; it is then an extremely simple matter to fill in both sides of the diaphragm with concrete, making a solid enclosing mass. The speaker believes that these features will soon come into very extensive use, and will receive considerable public attention.

Suppose there has been installed—by any method, no matter what—a simple diaphragm, say of steel, $\frac{1}{8}$ in. thick, with perfect watertight joints, capable of sustaining very little bending. It is obvious that it may easily be made efficient in very many cases in this manner. For instance, in a trench there are two lines of sheeting; as the excavation is commenced it can be carried down a foot or two without impairing even a very thin diaphragm. When this foot or more has been excavated, horizontal boards may be placed on edge—any scrap timber may be used—then cut down another foot or two, and place another board. Then put in a cross-piece and set the bracing. Continue in this way and finally complete the excavation, siding it up with horizontal boards placed singly, exactly as in well digging, and covered by distributing pieces taking the struts as they may be needed.

Now, that construction can be made exactly as it is required, and may be as heavy as necessary, and it has the advantage of costing practically nothing, because none of that material is permanent, and timber and boards are generally on hand for other purposes. It does not require to be of any regular or specific size, but can be put in as required, and removed after the necessity for its use has ceased.

In many cases such a method of bracing is efficient and exceedingly economical, and precludes the necessity of extra weight in the pile itself.

Mr. Woodworth. R. B. Woodworth, M. Am. Soc. C. E.—History does not state who drove the first wooden pile. Herodotus* describes pile dwellings inhabited by Pæonians on Lake Prasias, in Thrace, but long before the days of Herodotus the lakes of Switzerland and the alluvial coasts

* Book 5, Section 16.

of Denmark were dotted with human habitations founded on wooden piles to protect the races of that day from the onslaught of human enemies or the beasts of the forest. The Romans were proficient in pile-driving. The first bridge constructed at Rome was called the Pons Sublicius or Stake Bridge, from the character of its foundations, and is said to have been built by Ancus Martius, the fourth king of the Romans, who succeeded Tullus Hostilius about 638 B. C. and reigned until 614 B. C. It was the bridge defended by Horatius Cocles against Lars Porsena and his Etruscans. The famous bridge built by Julius Cæsar* across the Rhine in ten days was also founded on piles, and an old print in the Musée de St. Germain shows that the piles were placed with what is now called "floating equipment." Mr. Woodworth.

These instances refer to round wooden piles, but, in like manner, the first use of wooden sheet-piling for coffer-dams has long since been forgotten. The advantages of wooden sheet-piling are its simplicity, the ease and convenience with which material can be obtained, and the possibility of doing the necessary cutting and fitting with the simplest of tools and by unskilled workmen. Its disadvantages are many. The formation of tongues by strips spiked to the edges of the planks prevents waste of timber, but these are not as good as the tongues and grooves formed in a planing-mill, as in ordinary wooden floor construction; at best, they are easily split, and leaks develop under water pressure. The disadvantages of wooden sheet-piling for coffer-dams are so great that in spite of its simplicity and convenience, its use had gotten into disfavor, and it was seen years ago that there were improvements in wooden sheet-piling which would be valuable enough to be covered by letters patent. These were issued to James A. Wakefield, of Chicago, E. R. Beardsley, of Chicago, W. de H. Washington, Assoc. M. Am. Soc. C. E., of New York City, G. H. Cavanagh, of Boston, and others.

These improvements have overcome the disadvantages only in part, even for coffer-dam construction. It is still true that the length of wooden sheet-piling is limited, and that it can be interlocked perfectly only in short lengths. It has to be crowded together under driving by beveling the edges, which increases the expense and, even then, does not produce water-tight joints. Slight irregularities in the driving, due to encountering boulders, increase the danger of leaks—which in deep driving, it is practically impossible to prevent—and in extended trench work or multiple piers the material becomes so battered and distorted that it can seldom be used for more than one or two installations. A single line of wooden sheet-piling is only practical and water-tight provided the line itself can be made thick and heavy. Under ordinary conditions it is preferable to drive two lines and puddle between them with alluvial soil, gravel, or sand, in order to

*Commentaries on the Gallic War, Book 4, Section 17.

Mr. Woodworth.

make a water-tight coffer-dam. The disadvantages of wooden sheet-piling in coffer-dam construction are greatly increased, and its use is attended with extreme uncertainty, in the construction of core-walls for diaphragm dams, which represents its most recent development.

These disadvantages, particularly in permanent construction, were known years ago, and engineers felt the necessity of having some more homogeneous and reliable material. Early experience in the manufacture and driving of cast-iron sheet-piling is given in a "Memoir on the Use of Cast Iron in Piling, Particularly at Brunswick Wharf, Blackwall," by Michael A. Borthwick, A. Inst. C. E.* This "Memoir" was reproduced entire by Charles Evan Fowler, M. Am. Soc. C. E., in his work on "Ordinary Foundations," Appendix 6. It may be well here to recapitulate and extend Mr. Borthwick's "Memoir," and to add some items of historic interest gathered in the course of an independent investigation into the development of metallic forms of sheet-piling.

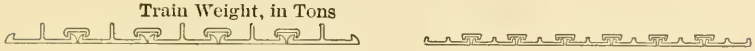
Previous to 1822 a Mr. Mathews had used cast-iron sheet-piles in the foundation of the head of the north pier of the harbor at Bridlington, England. These were of different forms, the most common one being shown on Fig. 13, reproduced from Mr. Fowler's work. It consisted essentially of round bearing-pile units connected by cast-iron plates dovetailing into each other; their length was about 8 or 9 ft., their width from 21 to 24 in., and the thickness of the plates was $\frac{1}{2}$ in. The real inventor of metallic sheet-piling was Peter Ewart, a civil engineer of Manchester, England, who, in ignorance of Mr. Mathew's proceeding, took out a patent for a new method of making a coffer-dam of cast-iron plates held together by cramps fitted thereto by dovetailed flanges and edges, Fig. 13. Mr. Ewart's patent is No. 4643, of 1822, and a careful study of it indicates that he had in mind a substitute for wooden sheet-piling, and understood very clearly that the substitute must be simple, easy to drive, and perfectly adequate for the service it had to perform. Therefore, he made ample provision for such adjustability as was needed to conform to the various conditions of driving and use.

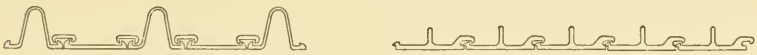
Mr. Ewart's piling was made with or without stiffening ribs, to suit conditions, and in general lengths of from 10 to 15 ft., spliced where necessary for deep driving. The cramps were also of various lengths, but made so that the joints should never be in the same horizontal line with those of the piles or plates with which they connected. To make the horizontal joints water-tight, or nearly so, three or four thicknesses of strong woollen cloth, or other suitable substance, soaked in a mixture of hot pitch and tar or other suitable composition, were to be laid flat on the edge of the lower portion of the pile or plate before the driving of the upper portion, proper provision, in the way of grooves, tongues, or tenons, being made for this purpose. Mr.

* *Minutes of Proceedings*, Inst. C. E., Vol. I, p. 195.

Mr. Woodworth.

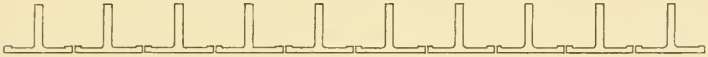
MATHEWS' CAST-IRON SHEET-PILING, 1822





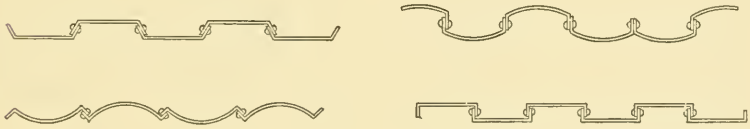
PETER EWART'S CAST-IRON SHEET-PILING, 1822

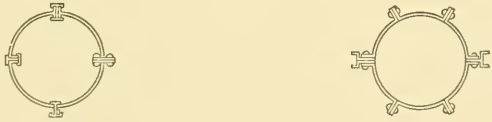
JAMES WALKER'S MODIFICATION OF EWART'S SHEET PILING, 1824



WILLIAM CUBITT'S, CAST-IRON SHEET-PILES, 1832

SIBLEY'S CAST-IRON SHEET-PILING, 1833





J.E. DOWSON'S ROLLED METAL PLATE USES, PATENT 1937-1863

ROBERT GOOCH'S IMPROVED WROUGHT-IRON SHEET-PILES, PATENT 2909-1863

Fig. 13.

Mr. Wood-worth. Ewart's coffer-dam contemplated the use of proper framework, such as waling pieces, to guide and support the cast-iron piles when necessary, to enable them to sustain the pressure of the water. These waling pieces were to be sunk in place, and the piling was to be assembled in position before driving. In order to prevent the pile-driving hammer from breaking the cast-iron piles he provided cushioned hoods of hard wood hooped with iron to prevent crushing under impact. Where the line of coffer-dam was extensive, provision was also made for expansion and contraction; the coffer-dams were strengthened also, where necessary, with banks of earth, clay, gravel, or puddle, as is done in the case of other coffer-dams. When the plates or piles had been in the wet for some time and were united strongly by the effects of rust, in addition to the pressure of the cramps, and it became necessary to withdraw the piles on the completion of the coffer-dam, a few cramps were to be broken off by a strong iron bar with a conical or properly shaped steel point driven down into the cavities.

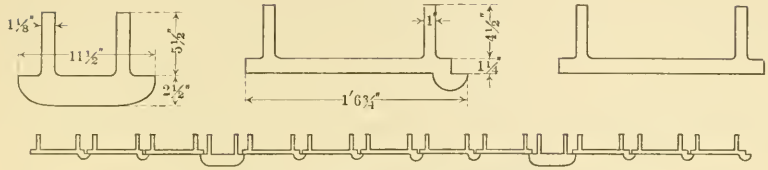
From this description it will be noted that Mr. Ewart had in mind metallic sheet-piling as a tool to be used over and over again as a part of a contractor's regular equipment, and Mr. Borthwick states that such piles were still in use in 1836, by the New River Company, at Broken Wharf, four sets being generally kept on hand.

Mr. Ewart's piling was used in a modified form in 1824 by James Walker, a Fellow of the Royal Societies both of London and Edinburgh, and a member of the civil engineering firm of Walker and Burges, in the construction of the return end of the quay wall at Downes Wharf, St. Katherine's. It will be noted from Fig. 13 that, while Mr. Ewart's cast-iron sheet-piling possessed a true interlock in both directions, the form used by Mr. Walker interlocked in the transverse direction only, and that imperfectly, and thereby constituted a departure from the true line of development.

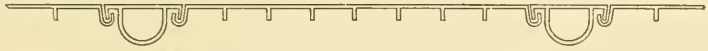
In 1832 William Cubitt (a Fellow of the Royal Society and of the Royal Asiatic Society, a Member of the Royal Institution of Architects, and Vice-President of the Institution of Civil Engineers in 1841) drove cast-iron sheet-piles in Tee form, of his own design, Fig. 13, at the east entrance of the Norwich and Lowestoft Navigation. These piles did not interlock, but had tapered and beveled points so as to crowd together under driving in exactly the same manner as wooden sheet-piling, and their success depended very largely on the accuracy of the driving and not on their mechanical construction.

In the work done by Mr. Sibley, in the construction of an iron wharf in the Lea Cut, at Limehouse, sheet-piling was discarded altogether, and the work consisted of flat plates let down in grooves on the sides of guide piles of elliptical form, as shown in Fig. 13; and this form of construction, modified as to details, Fig. 14, reappears in several later installations, the most important of which was the quay wall,

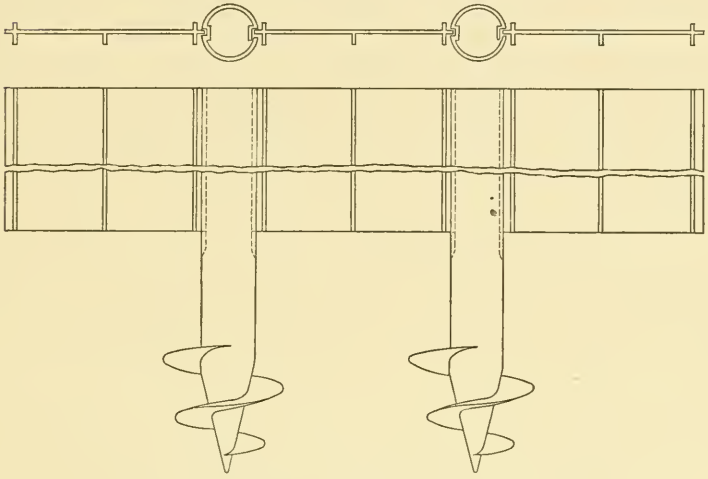
Mr. Woodworth.



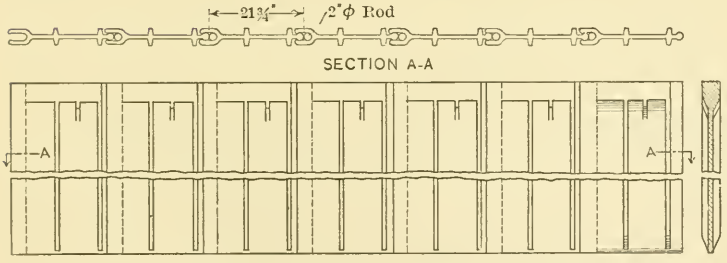
WALKERS' CAST-IRON SHEET-PILING, EAST INDIA DOCK, 1834.



CAST-IRON SHEET-PILING, CHELSEA BRIDGE, 1853.



CAST-IRON PILING, WATERLOO BRIDGE, 1864



SECTION A-A

CAST-IRON SHEET-PILING, BARRAGE WORKS, ESNEH AND ASSIOUT, 1908.

FIG. 14.

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constructed by Messrs. Walker and Burges, on the Thames in front of the East India Dock at Blackwall, since named the Brunswick Wharf, in which about 900 tons of cast iron were used. This is fully described in Mr. Borthwick's "Memoir." The success of this form of construction interfered beyond question with the use of metallic sheet-piling, and the further use of cast iron was probably decreased by the known deficiencies of this material and its unsuitableness for the resistance of impact and tensile stresses.

In 1857 Thomas William Kennard applied for a patent on "improvements in metallic piles," File No. 45; the invention received provisional protection only, and the application was never completed. There is no sketch attached to the provisional specification, but it appears that Mr. Kennard contemplated construction on the lines of the Sibley type, and there is a possibility also that there is a connection between this provisional specification and Patent No. 1332, of 1863, issued to Howard John Kennard for "improvements in the construction of wrought-iron cylinders for piers or piles to bridges, viaducts, or for other foundations or structures where the sinking of cylinders is required." This latter patent covers the cylinder method of submarine foundations.

William Humber*[*] describes the Chelsea Bridge, built under the supervision of Mr. Thomas Page, the piers of which were completed in 1853. The bridge itself had a total length of 704 ft., and was 47 ft. wide, with three clear spans of 166½, 333, and 166½ ft., respectively. The piers were 88 by 19 ft. The foundations were timber piles, driven on 3-ft. centers, cut off near low-water level, and sheeted with cast-iron piling composed of a tubular and a sheet-piling section driven to low-water level, Fig. 14; the tubular sections were 27 ft. long, and were connected by sheet sections driven 20 ft. below low-water level. The form of the pier was rectangular with elliptical ends, and the cast-iron piling was driven to prevent underscour by the current.

Mr. Humber, in discussing the use of sheet-piling for ports and harbors, states† "It has also been proposed to drive a row of cast-iron sheeting piles to a sufficient depth to guard against any subsequent scour of the water in front, the tops of the piles being driven to the level of low water;" he also gives a reference to the *Mechanics' Magazine,* of 1863, page 508, indicating that the use of metallic piling was fairly well established in England. On Plates 35 and 36, Mr. Humber illustrates the construction of the steamboat pier at Waterloo Bridge, Thames Embankment, in which screw piles, from 20 to 25 ft. long, having grooves in their sides, were driven about 8 ft. apart all around the enclosure and connected by cast-iron sheeting, Fig. 14. The sheet-

* "Practical Treatise on Cast and Wrought Iron Bridges and Girders" (1857), p. 88 and Plate 50.

† "The Record of the Progress of Modern Engineering for 1865." E. and F. N. Spon, 1866, p. 13.

ing was 15 ft. 3 in. long and was pointed at the end with, in some cases, a projecting flange at the top for driving. This pier was 113 ft. long and about 48 ft. wide, and Mr. Humber says: "We had intended giving some particulars respecting the iron caissons but circumstances have transpired which prevent doing so at present." Mr. Woodworth.

Apart from Mr. Ewart's original invention, these forms of cast-iron sheet-piling were not truly interlocking and, therefore, were not more water-tight than wooden sheet-piling beveled and tapered to crowd together in driving; and the line of development was interfered with by the introduction, as already narrated, of a type of construction composed of tubular and sheet units.

The speaker has been unable to pursue the history of cast-iron sheet-piling in England further. It is worthy of note, however, that within the last four years cast-iron sheet-piling, 1 in. thick, has been driven at the Barrage Works of the Egyptian Government at Assiout. This piling, as will be noted from Fig. 14, interlocks perfectly, and is made water-tight by driving a round steel rod in the interlocking groove. In design, it corresponds very closely to the United States steel sheet-piling sections. The same type of cast-iron sheet-piling has also been used at the Esneh Barrage which the Egyptian Government has built across the Nile about 100 miles north of the great dam at Assuan. The entire foundations of the lock piers of this barrage are enclosed by two lines of cast-iron sheet-piling, 60 ft. 9 in. apart, driven parallel across the river.*

Coffer-dams of boiler plate were used on the Inch Garvie piers of the Firth of Forth Bridge, in 1884, and steel caissons as well as steel cylinder piers have been used more or less extensively since that time. Their expense is justifiable only when the material is to be retained as a permanent part of the structure. Movable steel coffer-dams have been patented by J. E. Robinson and others. Mr. Robinson's coffer-dams were not very successful, but in one case, at the Schuylkill River, they were used where an ordinary wooden coffer-dam had failed entirely, and under circumstances which were particularly trying. The expense of a movable coffer-dam constructed of steel angles and plates, such as Mr. Robinson proposed, is due to the high cost of fabrication and erection. The contractor, in most cases, does not require a permanent structure, but a set of tools which can be carried from place to place and re-used repeatedly, the first cost of such tools being amply compensated by the ability to use them in that way; and this, as already narrated, is exactly what Mr. Ewart had in mind when he took out his patent in 1822.

Sheet-piling of rolled material did not come into use in England until its success had been demonstrated in America. At the same time, it is desirable to record certain endeavors which have been made

* *The Engineering Record*, February 6th, 1909.

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in the right direction, as reflected at least in the history of the Patent Office, neglecting all substitutes for round piles and considering sheet-piling only.

Joseph Emerson Dowson, of Westminster, in Patent No. 1937, of 1863, endeavored to cover the "application of rolled metal plates to the formation of roadways, bridges, tramways, and other structures," and to apply the same in the formation of any and all land or marine structures or parts thereof, whether of an engineering, architectural, mechanical, or other character, among which was the formation of grooves or channels in combination with hollow shafts, columns, piles, struts, and the like, which combination would serve to hold in place slabs of stone, plates of metal, timber, or any other suitable material for retaining, sea and other walls. This patent has been referred to as a forerunner of modern metallic sheet-piling, but the interlocking groove is conspicuous by its absence (Fig. 13).

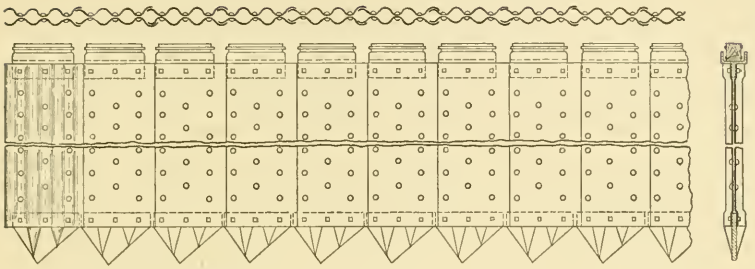
Patent No. 2909, of 1863, covers provisional protection of Robert Gooch on "improved wrought-iron sheeting piles," to effect which he used two sheets of wrought iron of like shape riveted together, one end of each sheet being bent up at right angles and the other having a hooked form, so that when riveted together they would form a dovetailed joint with the next set, the angle ends of one set fitting into the hooked ends of the following set, and so on, forming as it were an endless chain. No drawing was attached to this specification, but the probable form is shown on Fig. 13.

Patent No. 1005 was issued in 1864 to Josiah George Jennings, a sanitary engineer, of Lambeth, England, for "improvements in the construction of caissons, coffer-dams and similar structures used when forming foundations under water." Mr. Jennings' piling consisted of corrugated sheets riveted together in sections interlocking with each other to form a double wall, Fig. 15. These sheets were expanded at the bottom to receive a pile-driving point, and at the top to receive a cushion hood for the purpose of driving. This is the first instance of the use of corrugated metal for sheet-piling purposes.

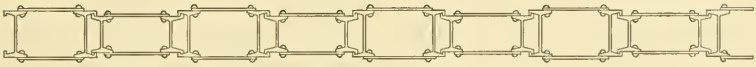
Patent No. 5254, issued to Frederick William Reeves, a civil engineer, of South Kensington, England, on December 15th, 1880, covered "an improved method of, and apparatus for, constructing foundations of submerged or partially submerged structures," which consisted in the use of box sections of beams and channels connected by plates and having interlocking projections on the outstanding flanges of the beams, channels, or plates. Mr. Reeves does not seem to have had very much experience in shop practice, otherwise his design, Fig. 15, would probably have covered sections having parts which could be assembled together by riveting.

The use of rolled-steel sections of established type, especially beams and channels, is reflected in the form of sections chosen by Mr. Reeves,

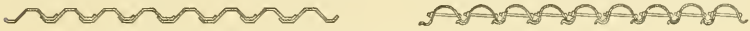
Mr. Wood-worth.



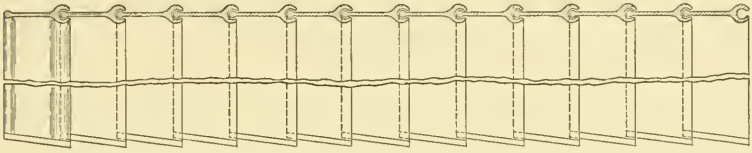
JOSIAH GEORGE JENNINGS' CORRUGATED SHEET-PILING. PATENT 1 005-1864.



FREDERICK WILLIAM REEVES' BEAM BOX-PILING. PATENT 5 254-1880.



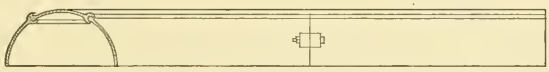
JAMES EDWARD WHITING'S CORRUATED PILING. PATENT 1 413-1885



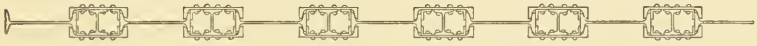
CHARLES A.F. GREGSON'S INTERLOCKING PILING. PATENT 18 238-1889.

FELIX PAPONOT'S IRON PILE PLANKS. PATENT 5 658-1883.

FRIEDRICH WILHELM LANG'S CAMBER-PLATE PILING. PATENT 18 935-1906.



LEWIS DODGE'S TUNNEL LINING. PATENT 103 028-1870.



WILLIAM HUNTER'S FABRICATED-BEAM PILING. PATENT 819 067-1906.

FIG. 15.

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and the true interlocking device, with a real appreciation of the problems to be solved, appears in Patent No. 5658, of December 6th, 1883, Fig. 15, issued to William Phillips Thompson, describing "improvements in or appertaining to sheet or other piling for making or protecting foundations below water level and other like purposes." Mr. Thompson was a solicitor, and the patent* was a communication to him from Felix Papenot, of Paris. Mr. Papenot's patent covers various forms of metallic piling, including the use of corrugated sections, but the most approved form is that shown in Fig. 15. It is to be noted that this piling, called "iron pile planks," was to be of rolled sections, in sizes and weights to suit conditions. The advantages of the iron pile planks were their adjustability; they could be used for excavating with a dredge and concreting the coffer-dam without unwatering; they could be used in building coffer-dams by excavating with a dredge, concreting up to the water level, and then pumping out and completing in the dry; they could also be used for sea walls and stockades in rivers. They could be made in single lengths or riveted together in long lengths, and for permanent work they were to be galvanized or painted with an inoxidizable coating. They were to be driven with the ordinary pile-driving equipment, some form of special hood being used to cushion the blow, and were to be made perfectly water-tight by driving a timber in the interlock, or by mastic or other impervious cement poured from the top.

Patent No. 1418 was issued to James Edward Whiting, of Karachi, Sind, India, in 1885, for "improvements in iron or steel bars or needles for regulators of sluices or waterways and for sheet-piling of coffer-dams," the forms of which are shown on Fig. 15. Water-tightness was to be secured by the pressure of the water itself forming close joints at the overlapping portions.

Since 1886 numerous patents have been issued in England covering various forms of metallic sheet-piling which it is not necessary to mention here; most of them are duplicates of patents previously issued in the United States to inventors whose activities in this direction are well known. In passing, however, it may be well to mention Patent No. 18 238, issued September 20th, 1890, but dated as of 1889, to Charles Arthur Fitzherbert Gregson, of Halton, England, for a form of sheet-piling of the ball-and-socket interlocking type, as shown in Fig. 15, the error in Mr. Gregson's construction being the failure to provide for proper clearance in the interlock and also to provide a method of rolling by which his piles could be manufactured. It is worthy of note also that for water-tightness he depended on the use of beveled edges and the crowding together of the sections consequent thereupon, as in using wooden sheeting. He also anticipated the necessity of having the piling section pointed.

* Fully described in *Scientific American Supplement*, No. 470, 1885, p. 7495.

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Outside of England, as far as the speaker has been able to obtain information, very little has been done in the manufacture of metallic sheet-piling, except in Germany, and that only of recent date, though it is altogether likely that a search among the records of the engineering societies of that country and the Patent Office would result in the discovery of a great deal of information not now accessible. Sheet-piling in the form of standard beams arranged in alternate longitudinal and normal positions has been driven, the longitudinal section being, say, from 15 to 18 in. in width, and the normal beam of a width sufficient for the entry of the flanges of the longitudinal beam into its web portion.

A very interesting form of plate sheet-piling, designated by the speaker camber-plate piling, has had considerable use in Germany, and has been discussed in a general way in England.* This form of piling, Fig. 15, was invented by Friedrich Wilhelm Lang, of Hamburg, Germany. It was patented in Germany under application date of August 25th, 1905, and in England under Patent No. 18 935, of 1906, and has been used at Hanover for the extensive coffer-dam foundation of the Provincial Revenue Offices. It is made of plates of the uniform width of 2 ft. and of thicknesses varying from $\frac{3}{16}$ to $\frac{5}{16}$ in., the edges of which are bent with specially constructed machines to form a labyrinth U-joint; and a series of rivets or small angle cleats, spaced from $1\frac{1}{2}$ to 2 ft. apart vertically, are provided to serve as guides for the plates while being put in position and to prevent lateral displacement while being driven. The labyrinth U-joint forms a strong interlock, which, if not practically water-tight at first, quickly becomes so by the natural sealing up of the clearances. The plates are bent to a radius of 27 in., which gives each sheet a camber of $2\frac{3}{4}$ in. Trials are said to show that it is possible to drive 35 yd. of this camber-plate piling in the time required to drive 14 yd. of ordinary timbering; also, that the short sections have been used from 100 to 150 times without deterioration.

Another interesting form of plate piling, of the trough-plate interlocking type, is Fig. 4, described by Mr. Gifford, of which some further particulars may be desirable. The inventor is Tryggve Larssen, of Bremen, Germany, and it is patented in Germany, France, England (No. 2204, of 1906), and the United States (No. 839 608, of December 25th, 1906). It consists of trough plates interlocking by hooked double Z-bars, and in weight of sections possesses a large measure of adjustability to different conditions of driving. On account of its peculiar arrangement, it is possible to obtain a large section modulus with the least possible expenditure of material; and, despite its lightness, it is easily driven and is claimed to be perfectly water-tight. More than

* *Transactions*, Junior Inst. of Engrs., March, 1907, in a paper entitled "Timbering of Excavations," by Charles W. Pettit.

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4 000 tons have been used in Germany since its introduction, particularly in the construction of docks and as retaining walls for canal work.

Most of the inventions heretofore described have been paper inventions only. Interlocking steel sheet-piling as it stands to-day is an American product. It is a gift to the world of the brains of American engineers dealing with problems of construction in the face of the necessity of constant adaptation to new conditions, and it is interesting to note that the application of sections now in use for sheet-piling purposes is quite different from that contemplated by the inventors. This is an indication that those who built, built better than they knew, which often happens in the use of new material, and that really valuable ideas are developed, extended, improved, and used for different purposes by the generations who succeed the originators.

Lewis Dodge, for example, in Letters Patent No. 103 028, of May 17th, 1870 (which is a forerunner of United States steel sheet-piling, and was granted for "improvements in the construction of tunnels and dams"), proposed to use his tunnel lining, Fig. 15, in making cofferdams to be filled with material for artificial stone, and extending sufficiently deep into hard bottom to protect against caving in when the excavation was made. He proposed to use the same construction for levees, docks, and piers, to prevent animals, such as muskrats, from burrowing in the embankment.

The Jackson type of steel piling is constructed under Patent No. 500 780, granted July 4th, 1893, to August Simon, of Gnadau, Germany, the primary application being to the use of steel piles to take the place of round wooden piles as ordinarily driven, and not to sheet-piling as such. Although Mr. Simon's invention comprises an improved form of beam or girder combined with special irons for use as piles or in building any structure whatever in which metal girders and beams may be used advantageously, a study of the patent indicates that he intended to use it for the lining of mine shafts in the work which in England is called "tubbing," for, in his description of his invention, he states:

"After the pile has been introduced into the fixed layer of ground that borders the quicksand or moving ground the hollow beams must be filled with oakum or moss. By this means a perfectly water-proof pile may be constructed, consequently the water and mud, silt or sand will be perfectly shut off. In brown coal mines it is very often desirable to drain the water-bearing ground on top. If this must be done, the hollow beams must only be filled with moss. After completion of the shaft and after the pumps have been definitely disposed, the moss is taken out again. It is also possible to sink a shaft in a dry state by shutting off the water for a time and yet the moving ground can be drained afterwards."

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As an afterthought, Mr. Simon adds: "I may state further that the described pile can be used for the construction of sluices or bridge building, water-works, and other foundations."

These forms, of what are called "sheet-piling" to-day, only became practical when contractors engaged in hydraulic engineering put them to use in directions not originally contemplated. The pioneer in the use of interlocking steel sheet-piling in the United States is Luther P. Friestedt. In June, 1899, he received a contract from the firm of Frohman and Japsen, architects, of Chicago, to lower the foundations of a two-story brick building at the corner of Sixty-third and State Streets, Chicago. In the excavation a stratum of quicksand was encountered, and it became necessary to drive sheeting around the cribwork to prevent any settlement or seepage that might undermine the walls and foundations. Wooden sheeting was tried, but failed. He then drove 10-in. channels in place of the wooden sheeting, and discovered speedily that it would be necessary to make some kind of an attachment that would hold the interlock of the channels together. He tried angle irons, and found that they held very well in one direction, but did not retain the channels in a rectangular position transversely. He then experimented with standard Z-bars, and found that the channels drove very much better with the Z-bar attachment than with others. The sheeting was in a crude form, of course, and considerable experimental work was necessary to make it a commercial success. The results of these experiments are covered by Patent No. 707 837, of August 26th, 1902, which claims improvements in the construction of docks, wharves, sea walls, facing of sea walls, caissons, coffer-dams, bulkheads, and other submarine work of the same general character. Mr. Friestedt justly claims to be the pioneer of the steel sheet-piling industry, and beyond question his large use of it in his own contracting work and his efforts in the extension of its use by others contributed to make it a commercial success.

As far as the speaker has been able to ascertain, the credit for the first driving of truly interlocking steel sheet-piling anywhere on a commercial scale is due to the contracting firm of George W. Jackson, Inc., which used the fabricated-beam type of steel sheet-piling, constructed under the Simon patent, in November, 1901, at the Randolph Street Bridge, Chicago.

From Mr. Friestedt's experimental units in 1899 the engineers and rolling mills of the United States have made of steel sheet-piling a thing of commercial importance which is beginning to be reflected by a large increase in the steel production of America, and has led to its application and use in all parts of the world. In 1907, for example, of 12 000 tons manufactured by the company with which the speaker is connected, 138 tons went to Canada for coffer-dam construction and lock work; 128 tons to Cape Town, South Africa, for

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temporary trench work in connection with the Selbourne Dry Dock at Simonstown; 653 tons to Brazil; 446 tons to the Municipality of Singapore, Straits Settlements; 207 tons to England for the reconstruction, principally, of the Buccleuch Dock; 138 tons to the Argentine Government; 286 tons to the Railway Controlling Bureau of Corea, Chemulpo. It may also be mentioned, as a matter of interest, that in 1908 the City of Mexico, in building a monument to commemorate the independence of that country, formed the foundations of that monument with concrete inside of a retaining wall of steel sheet-piling.

Types.—A few of the forms of steel sheet-piling which have been placed on the market are noted by Mr. Gifford, and vastly more, which have never been manufactured, nor indeed can be manufactured, in the light of present rolling-mill experience, are to be found in the files of the United States Patent Office. These various forms have been carefully considered in a paper by the speaker,* in which an attempt was made to classify them and to assign them names which would indicate in a general way the character of the material used and its form, and it may be well to summarize briefly and extend the observations made on these various types, in the light of further experience in their manufacture and use.

As far as information is at hand, the only types of steel sheet-piling which have been manufactured and used in the United States are: the Simon fabricated-beam type, used and sold by George W. Jackson, Inc., of Chicago; the interlocking beam clip type, also used and sold by George W. Jackson, Inc., under Patent No. 878 773, granted to Manley W. Cluxton; interlocking channel bar piling in its full length interlock, clip interlock, Fargo, and symmetrical interlock forms, manufactured and sold by the Carnegie Steel Company, and in the George E. Nye clip form, sold by the National Interlocking Steel Sheeting Company, of Chicago; the corrugated interlock type, sold by the Wemlinger Steel Piling Company, under patents of Lester R. Gifford, Assoc. M. Am. Soc. C. E., and R. V. Sage; the spring lock sheet-piling, invented by Frank W. Skinner, M. Am. Soc. C. E., and sold by the Canton Bridge Company, Canton, Ohio; Vanderkloot steel sheet-piling, under the patent of Mathias R. Vanderkloot; United States steel sheet-piling, manufactured by the Carnegie Steel Company, under the patent of Samuel K. Behrend; Boardman piling, rolled by the Lackawanna Steel Company; and Harold piling, rolled by Jones and Laughlin.

These various types have their distinct peculiarities, advantages, and disadvantages, and it may be well to discuss the principles of their

* *Proceedings*, Engineers' Society of Western Pennsylvania, Vol. 24, Part 1, February, 1908, and reprinted in *The Iron Age*, March 12th, 1908; in *The Industrial World*, March 9th, 16th, and 23d, 1908; and in *The Scientific American Supplement*, Nos. 1702 and 1703, August, 1908.

manufacture which make their use economical, and the lines which should govern the engineer in choosing a steel piling suitable for the requirements of actual service. These principles are the same as those which would ordinarily guide in the manufacture and choice of any other tool. Mr. Woodworth.

The advantages of the fabricated forms of steel sheet-piling, whether manufactured from beams, channels, or plates, consist in the ease with which the sections can be obtained, and the possibility of their manufacture in ordinary fitting shops or by machinery of small cost. Their disadvantage consists in the fact that, when they come in competition with shapes specially rolled for piling purposes, they are handicapped practically to the extent of the additional cost of the punching, riveting, bending, etc., necessary for their manufacture in the shop.

The earliest and simplest form of fabricated-beam type is that covered by Patent No. 500 780, granted on July 4th, 1893, to August Simon, of Gnadau, Germany, and manufactured by George W. Jackson, Inc., which has made numerous improvements thereon in the way of providing special junction pieces and the further simplification of this type, which consists essentially of two standard beams or channels connected by bolts and spreaders to form what might be called "box" piles which are connected in a straight line by standard beams and channels, the flanges of the single beams forming this connection interlocking with the flanges of the beams or channels forming the box, and, therefore, reproducing in steel the earlier forms of construction used in England by Sibley, Walker, and others, and of which it has been said that they constituted a departure from the true line of sheet-piling development. This type, Fig. 1, affords large possibilities in heavy subaqueous work, but is deficient in its ability to furnish sections of light weight for ordinary coffer-dam and sewer construction; therefore, it is not truly economical as a substitute for wooden sheet-piling, except in so far as there is the possibility of frequent use on a particular installation. It is made water-tight by puddling clay in the box pile, which is objectionable, and the obviation of which is the purpose of Patent No. 909 549, granted January 12th, 1909, to Manley W. Cluxton, Engineer with George W. Jackson, Inc. Another serious objection to the fabricated-beam type is the difficulty of driving, which necessitates the use of special pile points and increased expenditure as compared with other simpler forms. It may be noted, as an indication of the necessity for experience in successful invention, that William Hunter, of Kincardine, Ont., has covered a further development of this type in Patent No. 819 067, which consists essentially of a series of steel columns, built up of beams and channels and connected by heavy I-beams, which would be extremely difficult to drive and about four or five times as heavy as needed in ordinary sheet-piling

Mr. Woodworth.

work, but which, after it had reached its final position, would have the strength of Gibraltar.

The excessive weight of the fabricated-beam type led inventors to consider the use of beams aligned successively with the top flange of one against the bottom flange of the other, and connected by rolled or malleable clips, as covered by Patent No. 878 773, granted to Manley W. Cluxton, and Patent No. 877 588, granted to George E. Nye, as shown in Fig. 1. A quantity of the Cluxton beam-clip type has been driven in the construction of a 40 by 132-ft. coffer-dam at the Steele-Wedeles Building, in lengths of 45 ft. This piling requires very little shopwork, and offers less resistance to the soil than the Simon fabricated-beam type. The speaker, however, does not believe a piling of this type could be made water-tight, and it is also subject to all the disadvantages of the use of clips, as will be further explained when the form of steel piling interlocks is considered.

One of the advantages of the Simon fabricated-beam type consists in the salvage of the plain beams which connect the box piles. The same consideration appears also in the original type of Friestedt interlocking channel-bar piling (Patent No. 707 837). This form, Fig. 1, came into successful use immediately after its introduction, and has had extensive application in building coffer-dams, retaining walls, core-walls for dams, and every other construction in which steel sheet-piling has been used. It resists water pressure remarkably well, as particles of silt, gravel, etc., are carried into the interlock and form a water seal; and if leaks develop they may be stopped very easily by the application of silt to the outside surfaces, or by using oakum or other packing material inside. In the original manufacture of Friestedt interlocking channel-bar piling, the single plain channel was weaker than the adjoining member with the two Z-bars riveted thereon, owing to its small radius of gyration and the consequent tendency to buckle under heavy driving. The first to discover this weakness was William G. Fargo, M. Am. Soc. C. E., who used a considerable quantity of it in a steel diaphragm core for the dam of the Grand Rapids-Muskegon Power Company at Grand Rapids, Mich., under conditions of difficult driving, in long lengths, through sand, gravel, and boulders, in an eroded river valley. To obviate this disadvantage, Mr. Fargo had fabricated a quantity of piling which differed from that covered by the Friestedt basal patent in having a single Z-bar riveted to each piece, instead of two Z-bars riveted to alternate sections. Thus he succeeded in making each piece of the same strength, and found that the most difficult driving could be accomplished satisfactorily. His ideas have been covered by Patent No. 805 533, of November 28th, 1905, Fig. 1.

Under difficult driving, however, the free side of the Fargo section is subject to the disadvantage of becoming battered under the blows

of the hammer, and there is nothing to hold the alternate sections in alignment except the pressure of the material and the friction in the pile-driver leads. The former disadvantage is immaterial in the driving of permanent installations, but becomes a matter of great importance when the piles have to be drawn and re-driven in temporary construction. Consequently, the speaker has devised a further improvement, which consists in riveting a single full-length Z-bar on each section at one edge, with a short piece at the other edge of each member, at the top only, the function of this short clip piece being only to hold the material in alignment and to distribute the blows of the pile-driver more uniformly over the section than is done either in the Fargo or in the original Friestedt type. This gives a perfectly symmetrical section which possesses a high degree of stiffness. This form, Fig. 16, is the strongest and stiffest steel sheet-piling made in the United States, and, as standard channels and Z-bars are used, it can be varied in weight and strength to meet almost any conceivable condition. The trade name of this piling is symmetrical interlock channel-bar piling, and it is covered by Patent No. 888 135, of May 19th, 1908. Mr. Woodworth.

In the endeavor to obviate the weight due to the use of Z-bars extending the full length of the channel and forming a continuous interlock, the idea has arisen that it might be possible to use short pieces of Z-bars riveted at the top and bottom, and in long lengths also at the middle. This has given rise to the clip interlock form of interlocking channel-bar piling. Patent No. 912 949, of February 16th, 1909, granted to Arthur A. Friestedt, covers the use of rolled Z-bars, and in Patent No. 860 053, of July 16th, 1907, granted to George E. Nye, the clips are formed, not of rolled Z-bars, but of malleable castings approximating the Z-bar shape. A small quantity of each section has been driven in an experimental way, but without entire satisfaction, the reason for which will be explained when the form of steel sheet-piling interlocks is considered.

Wemlinger steel piling, Fig. 1, referred to by Mr. Gifford, and manufactured under patents of Lester R. Gifford and R. V. Sage, Nos. 766 131, 766 132, and 766 147, all of November 29th, 1904, is designated by the speaker as the corrugated interlock type, in which the sheets are corrugated as in roofing and the interlock is formed by a special rolled shape fitting closely over the apex of adjoining sheets. The use of this type commends itself because of the possibility of adapting the thickness of the plates to the conditions of transverse strength, the stiffness of the corrugated section, and the closeness of the interlock. As far as the speaker has been able to obtain information, the Wemlinger steel piling has only been used in sewer-trench work, where probably the largest field for its application will be found, and in the construction of the core-wall of the dam of the Uncas Power Company, at Norwich, Conn. Therefore, it has not yet been tested

Mr. Woodworth.

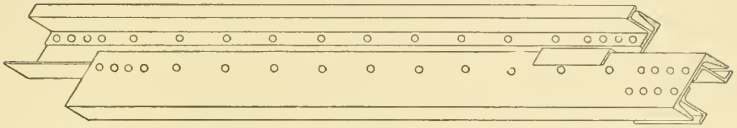
in situations where its ability to resist the percolation of water is really needed, and it is a question of very grave doubt whether it will ever be possible, by methods of rolling, to avoid irregularities in surface, and to make by mechanical means alone an absolutely water-tight structure. The driving at the dam of the Uncas Power Company seems to have been very difficult; at the same time, 4 000 blows of the steam hammer to secure a penetration of 18 ft. is highly excessive, and would indicate a comparatively high driving charge. In point of manufacture, this piling also suffers in comparison with other forms, both rolled and fabricated, in the necessity and cost of corrugation in addition to the shopwork.

Spring lock steel sheet-piling, Fig. 1, invented by Frank W. Skinner, M. Am. Soc. C. E., is covered by Patent No. 842 120, of June 22d, 1907, and others of later date. The essential idea is to provide adjoining plates with their ends curved to slightly different radii which in driving compels the sheets to lock closely to each other. With this type it should be possible to use the same interlocks for different thicknesses of sheets. The disadvantages would be the necessity for the manufacture of special sections, the weakness of the sheets in the interlocks, and the necessity, in connection with the piling itself, of some mechanical device, such as a follower, to go down with the sheets and hold them in position until bracing can be done. It is very apparent that the use of these followers calls for not only increased expenditure, but delay in the driving of the piling; and the disadvantage which attends the use of composite forms of sheet-piling composed part of steel and part of wood raises a question whether, if it is necessary to batter, splinter, and destroy a lot of wood to put down steel sheets, it were not better after all to use wooden sheet-piling and be done with it. This form of steel piling should give very good service in trench work. Its radius of gyration is necessarily small, and therefore it would seem that it is not adapted for permanent construction or for difficult driving. It is very likely that it would show a fair degree of water-tightness.

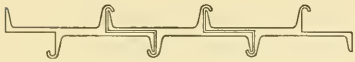
This completes the consideration of those forms of steel sheet-piling which have been constructed of ordinary commercially-rolled sections by fabrication and bending, and have actually been driven. All these types carry with them increased cost over specially-rolled sections, on account of the shopwork, corrugating, etc., necessary in their manufacture. In their development there has been necessary only the application of engineering knowledge and fitting-shop practice in the use of material ready to hand. In the development of specially-rolled forms of steel sheet-piling, which, after all, is the ideal type of construction, it has been necessary that engineering knowledge and experience should be supplemented by practical rolling-mill experience.

A small quantity of steel sheet-piling was manufactured in 1906

Mr. Woodworth.



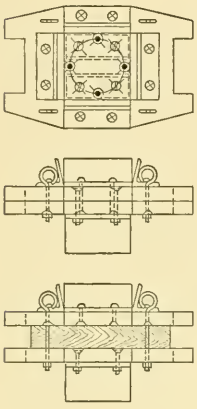
SYMMETRICAL INTERLOCK CHANNEL-BAR PILING. PATENT 888 135-1908.



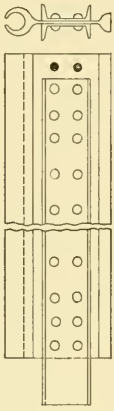
VANDERKLOOT PILING PATENT 763 526-1904

VANDERKLOOT PILING AS ROLLED

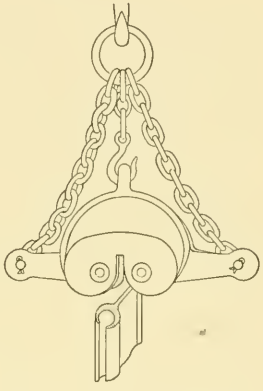
HAROLD BEAM PILING. PATENT 901 241-1908.



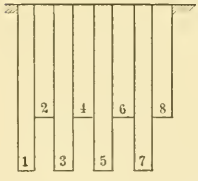
STRUCTURAL STEEL DRIVING CAP. PATENT 914 098-1909.



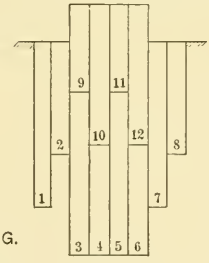
FOLLOWER FOR DRIVING PILING BELOW LEADS OF DRIVER.



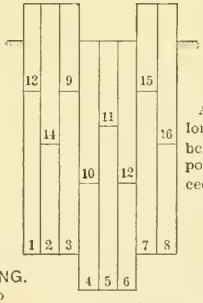
CURTIS SHEET-PILING PULLER.



FIRST STAGE OF DRIVING.
Drive each piece its full length.



SECOND STAGE OF DRIVING.
Drive a short length on top of a long one, etc., to within about 1 feet of final position.



THIRD STAGE OF DRIVING.

A combination with a long pile on top should be driven first to final position, then each succeeding combination.

FIG. 16.

Mr. Woodworth.

and 1907 by the Jones and Laughlin Steel Company, under Patent No. 763 526, of June 28th, 1904, granted to Mathias R. Vanderkloot, of Chicago, known as the Vanderkloot steel piling, and covering a form of rolled section in which an interlock is formed by bending over into hooks the flanges of what starts from the mill as an unsymmetrical beam section. The form of the Vanderkloot piling, Fig. 16, as actually rolled, however, represents quite a departure from that shown in the patent. This piling drove easily at the Berrien Springs Dam of the Indiana and Michigan Power Company, and photographs indicate its success. The disadvantages of the section, however, were the tightness of the interlock, the lack of proper clearance and flexibility, and the lack of any means by which the piling could be rendered water-tight. As the cost of manufacture of this piling was extremely high, it has been discontinued.

It may be said, in a general way, that any form of piling which requires special rolling-mill equipment, and the manufacture of which is attained only at a high rolling cost, is obviously barred from commercial uses. Intricate interlocking systems, and dovetailed and reversely bent forms, such as are to be seen in quite a number of patents, cannot long merit consideration. The ideal piling must be economical, from the standpoint of manufacture.

Practically 65% of the piling sold to-day is covered by Patent No. 639 884, granted to Samuel K. Behrend, of Washington, D. C., on December 26th, 1889, and is known commercially as United States steel sheet-piling. This piling, Fig. 1, incorporates the advantage of a ball-and-socket joint, insuring almost perfect flexibility. This was the idea advanced by Mr. Dodge in Patent No. 103 028, of 1870, for "improvements in the construction of tunnels and dams," and, as already indicated, reappears in the patent granted to Mr. Gregson, with this difference: that Mr. Behrend realized the need of sufficient clearance in the interlock for ease of driving, and the necessity of using in the interlock a packing substance between the adjacent edges, to be expanded by moisture for the formation of a water-tight joint.

The manufacture of this form has also brought forth novel ideas in roll turning. Patent No. 771 426, in which the essential idea was to form an interlocking member by turning over a beam flange so as to form an interlocking curve, was granted to Walter G. Harder on October 4th, 1904. Immediately on its issuance its infringement with the Behrend patent was noted. The matter was taken into court, where it was testified that steel sheet-piling, as covered by the Behrend patent, could not be rolled by any method known to the art. In spite of this, however, the Behrend piling was rolled successfully on December 23d, 1904, by a special method invented by Edwin E. Slick, covered by Patent No. 852 984, granted May 7th, 1907, and known at the mills as the butterfly method. It is this method of rolling and the co-

operation of practical rolling-mill experience which have made possible the development and success of United States steel sheet-piling. Since the date of its first rolling, this piling has been tried out in all classes of construction, under the most favorable as well as the least favorable conditions of driving, and its adaptability to all these uses has been demonstrated. This and the symmetrical interlock channel-bar piling may be considered as standards of the rolled and fabricated types. Mr. Woodworth.

As far as the speaker is aware, the patent covering what is known as the Lackawanna steel sheet-piling (named from the company which makes it) has not yet been issued. The piling itself, Fig. 1, is understood to be the invention of Mr. Boardman, and represents what may be called a drawbar type, owing to its resemblance to the drawbar heads in use in the modern coupler attachment of standard freight cars, a form very similar to which was covered by Patent No. 829 399, of August 28th, 1906, issued to Truman Hill, of Chicago. The Lackawanna steel sheet-piling was first rolled successfully about April 1st, 1908, and has been given wide advertisement by its use in the construction of the coffer-dam for the United States ship lock at Black Rock Harbor, Buffalo, N. Y. It is a very strong, stiff section, drives with considerable ease, and is entirely suitable for all ordinary sheet-piling purposes. It also possesses great strength in the interlock, which will be mentioned later.

The Jones and Laughlin Steel Company has recently made a form of sheet-piling, Fig. 16, under Patent No. 901 241, issued to James J. Harold, of Jersey City, N. J., which is constructed of standard beams arranged with longitudinal reference to each other, and interlocked by the bent flanges of a similar beam section normal to the junction of adjoining sections. An experimental unit of this type was driven at the Black Rock lock, but otherwise has not yet been used, as far as known to the speaker. The assemblement is very strong transversely, and can be made to suit any condition by the rolling of special interlocking pieces. It also has a high margin of salvage, as the plain beam sections may be withdrawn for other purposes. In common with the Simon fabricated-beam type, it represents the development of the box-pile type introduced by Sibley and Walker, and, therefore, is subject to more or less of the disadvantages of difficult driving; moreover, it is not economically adapted to anything but heavy and difficult work; the separate interlocking sections must preferably be assembled in position before driving, as they are too flexible to go down in long lengths without buckling under the hammer. Light sections of this form, for sewer and trench work, cannot be obtained without the manufacture of special forms of I-beams; therefore, it is not likely to come into general use.

The Interlock.—The economical section of steel sheet-piling should be easy to drive and easy to withdraw. Looseness in the interlock is

Mr Wood-worth. here indispensable, and experience in the manufacture of both fabricated and rolled sections indicates that there should be at least $\frac{1}{8}$ in. of clearance in the sections; the clearance, however, should be kept down to a minimum, as a very little additional clearance means that much more opportunity for water to come through the coffer-dam, if the piling is used for that purpose. Plenty of clearance in the interlock also allows some slight play in driving the piling past boulders or other obstructions, and, for that reason, is desirable. The ability to turn angles and corners by the mere matter of looseness in the interlock is not of paramount importance, and therefore its absence has in no way militated against the use of the fabricated forms of steel sheet-piling. In heavy straight work, under difficult conditions of driving, alignment can be maintained very readily, and the driving can be performed successfully, because the piling will split or move aside boulders of considerable size, and will go through submerged timbers with ease by reason of its stiffness, its weight, and the weight of the hammer necessary under such conditions. In light sewer and trench work, boulders and submerged timbers are very rarely encountered. In fabricated sections, special corner pieces as a rule cost but very little more than the ordinary plain sections, and their manufacture causes no particular delay in the fabrication of an order.

In circular assemblements, however, the advantages of a flexible form of interlock become evident at once. The diameter of the smallest circle that can be driven with the 15-in. 38-lb. symmetrical interlock channel-bar piling, for example, without bending the sections, is 39 ft. On the other hand, owing to its form, the rolled section is readily adaptable to construction of this class. There is a play of about 22° in 12-in. Lackawanna steel sheet-piling, thus permitting the formation of a circle with 17 pieces, or about 72 in. in diameter, corresponding to the 12-in. 40-lb. United States steel sheet-piling section. United States steel sheet-piling sections, of 12-in. 35-lb. and 6-in. 11-lb., may also be driven in circles of 54 and 30 in. diameter, respectively. Therefore, they have come into extended use in the construction of pump-wells, circular coffer-dams, etc., etc. They may also be used to build rectangular coffer-dams without specially bent corner pieces, though, as a general rule, engineers and contractors prefer to use them rather than increase the over-all dimensions of the structure and thereby also the cost of the excavation.

The form of the interlock itself is of considerable importance, as it has to do with the question of strength to resist forces in a longitudinal direction which sometimes occur in actual use, and it is very clearly made out that the contact between the head and the socket should be by points and not by surfaces, for the reason that thereby wedging action is prevented and bending movements, due to slight deviations from a straight line, are eliminated. It was found

possible to increase the efficiency of the United States steel sheet-piling in the longitudinal direction 50% by a very slight change in the shape of the head; and, whereas, under the old type of construction, indicated in Fig. 1, this section would stand a pull of 6 600 lb. per lin. in., in its new form it has shown in experiments a value of 12 120 lb. Mr. Woodworth.

In reference to the Vanderkloot piling, the speaker understands that the lack of flexibility and the difficulty of obtaining it under present rolling-mill conditions are the reasons for its retirement from the market. The development of the art of rolling has made possible the successful manufacture of peculiar shapes of interlocks, and, of course, further improvement in this direction may be expected. The ideal steel sheet-piling, however, must necessarily be a simple section, with symmetrical and interchangeable units, each of the same strength.

Apart from its form as a factor of economical manufacture by the rolling mill, the ideal interlock will necessarily be continuous; that is, the assembled sections must interlock throughout their entire length, and the use of clip forms of construction, while possible under easy conditions of driving, are to be avoided in the purchase of tools intended as a permanent part of the contractor's pile-driving equipment. This has been indicated in the reference to the Arthur A. Friestedt clip form of Friestedt interlocking channel-bar piling and the beam-clip types invented by Manley W. Cluxton and by George E. Nye. The driving of piling of these types to refusal necessarily tends to cause the channels or beams to buckle about their middle and to open out, thus destroying any effective interlock and, in subaqueous work, resulting in excessive leakage which cannot be stopped except by expensive means, which causes undue delay in construction. Experience in their manufacture and use most emphatically demonstrates the futility of endeavors in this direction to cheapen the cost of construction, and emphasizes the importance of the continuous interlock.

Longitudinal Strength.—From recent discussion it might appear as though strength in the interlock to resist pulling apart was a matter of primary importance, and that it should take precedence over stiffness in driving and transverse resistance. Under conditions of unequally distributed earth and water pressure, it is apparent that distortion in the alignment will naturally tend to create tension in the interlock, and that there should be sufficient material here to take care of all such stress. Strength in the interlock, stiffness in driving, and strength when interlocked are requirements which are indispensable. At the same time, only twice in the speaker's experience has it happened that unusual strength was needed in this direction. In one case a contractor built a coffer-dam of United States steel sheet-piling in which the bracing gave an unsupported length of 14 ft. from the bottom of the piles to the first line of waling timbers, which was very much more than the section modulus of this material would allow.

Mr. Woodworth.

The water rose very rapidly in the river, and the coffer-dam collapsed by bowing in at about the fifth pile from each corner and the pulling apart of the piling in the interlock. The pressure here was enormous, but, had the piling been stronger, the collapse might have been prevented in spite of the failure of the contractor to brace the structure properly.

In the work done by MacArthur Brothers in the construction of the coffer-dam for the lock at Black Rock Harbor,* the question of strength in the interlock became a very vital one. Owing to the character of the construction, the piling in the wall next to the lock was not of sufficient strength, considered as a beam, to resist the unsupported earth pressure from the clay puddle. It became necessary, therefore, to consider the tension in the interlock, which might be developed by this earth pressure, and a very careful investigation was made to determine the type of steel sheet-piling to be used. The calculations seemed to require a pull in the interlock of 5 000 lb. per lin. in., which, with a factor of safety of two as against the elastic limit, would give an ultimate tensile strength of 10 000 lb. per lin. in. Careful experiments were made on testing machines to determine whether or not any piling on the market came up to this requirement, and, while the contract for the piling in the last analysis was awarded solely on the ground of commercial considerations, the results of these tests are of value as indicating what may be expected under similar conditions in the future.

It was found that the four different types of piling tested gave the following values for tensile strength as the average of three tests:

Friestedt (light type)	1 114	lb. per lin. in.
United States steel sheet-piling (35-lb.)	3 842	" " " "
Lackawanna piling	9 746	" " " "
Jones and Laughlin (as reported by them)	7 000	" " " "

In view of the unfavorable showing of the Friestedt interlocking channel-bar piling and the United States steel sheet-piling, the manufacturers thereof continued these tests and extended them, reaching the following results:

15-in. 44-lb. Friestedt piling	1 502	lb. per lin. in.
Friestedt special piling	2 252	" " " "
12-in. 35-lb. United States steel sheet-piling	3 569	" " " "
12-in 40-lb. United States steel sheet-piling	6 060	" " " "
Simon fabricated beam-piling	2 022	" " " "
Lackawanna steel sheet-piling	9 584	" " " "
Harold piling (Jones and Laughlin)	7 271	" " " "

* *The Engineering Record*, April 3d, 1909, p. 385.

With the exception of the special Friestedt section, these sections weighed approximately 40 lb. per sq. ft., and the results indicate the high advantages possessed by rolled sections, the slightest deviation from a straight line in the application of the pull on the testing machine resulting, in the case of the fabricated sections, in transverse bending moments which crippled them and thus materially decreased their resistance to direct tension. Mr. Wood-worth.

On the ground of investigations on their own testing machines, the manufacturers of United States steel sheet-piling guaranteed that they would produce a section to develop the desired tensile strength of 10 000 lb. per lin. in., and that type of piling is now manufactured with a modified design of head shown by experiments to be the most satisfactory for the resistance of longitudinal stresses. Sections tested have withstood a pull of 12 120 lb. per lin. in., and the average of sixteen pieces tested was 9 437 lb. An average of six other tests, with lower minima and maxima, shows a resistance of 10 428 lb. per lin. in., from which it is apparent that in this style of section it is possible to secure any strength which may be necessary. It is to be regretted that results of the same careful kind are not accessible for the corrugated and the spring lock types of sheet-piling. As already explained, the necessity for great strength in the interlock has only arisen twice in the writer's experience, which goes back to the very inception of the steel sheet-piling industry, and a consideration of this kind need not, therefore, be made a part of a set of specifications covering ordinary coffer-dam construction or other work in which steel sheet-piling is to be used. Mr. Gifford, therefore, has wisely not mentioned it in his specifications.

Transverse Strength.—As far as concerns the strength of steel sheet-piling to resist earth or water pressure, it may be said at the outset that when interlocked its strength is quite different from that during driving. In the former position it must have strength similar to that possessed by any other beam loaded equally or unequally with the earth or the water pressure, and the strength of the steel can be calculated by the known laws of flexure from the section modulus of the material. Under conditions of water pressure, the problem is comparatively simple, being subject to the laws of hydrostatics.

The method given by Mr. Gifford deals with the comparatively simple case of a coffer-dam subject to water pressure only, in which the piles are braced at the top with a single set of waling timbers, and the conclusions reached are identical with those given by Mr. Fowler.* This design does not conform to, and would very seldom indeed be met in, actual practice; neither would the construction shown be the most economical. In the use of steel sheet-piling, the most economical form of construction is found when the length of the piling above the

* "Ordinary Foundations," Chapter 5.

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first set of waling timbers is as much as possible, considering the piling as a cantilever beam loaded with water pressure, which (by the usual formula) can be considered as concentrated one-third of the way up from the waling frame. In the next section, as the coffer-dam deepens, the piling is to be considered as a beam supported at each end by the waling timbers, with this difference, that, owing to the reactions from the cantilever end, there will be a complicated stress near the first waling frame. The calculation of these stresses and the determination of the size of the waling timbers, while not very simple, is the ordinary proposition met in the construction of all coffer-dams.

As far as earth pressure is concerned, conditions vary so widely that no fixed principles can be set down, because the whole subject of the timbering of excavations and shafts is a question of engineering interest which has not yet met with a satisfactory solution. The reactions due to earth pressure, and in general how this earth pressure acts, are not known. In quicksand the material may act exactly like water, in which case the pressure would be determined by the weight of the material concentrated at one-third of the unsupported length of the member. It is apparent, however, that in driving piling through undisturbed strata, this condition is not attained, as each successive foot of penetration causes the piling to pass into strata which become firmer and firmer the deeper the piling penetrates until rock is reached. For example, the material may stand at the top of the shaft at $1\frac{1}{2}$ to 1 for the first 5 ft., the next 5 ft. at 1 to 1, the next 5 ft. perhaps at $\frac{1}{2}$ to 1, until a point is reached where there is practically no pressure on the piling from the outside. It appears reasonable to suppose that bracing may be made lighter as the depth of the installation increases, and yet any theory based on the homogeneous character of the soil will be vitiated as soon as either hardpan or quicksand is encountered. The whole question at present is a matter of experience and judgment. It is better to trust in strong bracing than to take chances of serious failure; not that the piling would be destroyed by almost any conceivable failure, but because of the delays and expenditures incident thereto due to lack of judgment.

There is danger in using metal which is too thin. Sheets of paper can be used to hold in place small piles of sand, but thin sheets of steel can only be used economically where the depth is not great and where the soil is loose; and yet there are inventors who gravely advocate the use of practically plain sheets of steel $\frac{1}{8}$ in. thick, and claim that they can be driven more easily and correctly than 4-in. tongued and grooved plank in any possible soil from quicksand to hardpan. It is pretty clearly made out that under ordinary conditions a 33-lb. or 35-lb. pile can be driven through almost any class of material up to 35 ft., and that a 38-lb. or 40-lb. pile can be driven and, with proper interior bracing, will successfully withstand ordinary earth and

water pressure up to 50 ft. It has also been proven by experience that, if material of lighter weight is to be driven, it can only be done at the risk of failure, or by the use of such an amount of bracing as would not be economical. Economy in total cost of construction is better reached by the use of good heavy piling and light bracing than by light piling and heavy bracing. The two things go together, and each separate problem calls for its own separate solution. Mr. Woodworth.

Section Modulus.—The section modulus of steel sheet-piling should not be calculated on the basis of the foot width of the piling in place, but from center to center of the integral sections, which brings the calculations into line with what is done by the manufacturers in the publication of the properties of standard beams and channels. In calculating the section modulus of the piling sections, it very often happens, especially in the case of unsymmetrical sections, that the center line of the assemblement is not the center line of the individual members, and it is necessary to refer all the calculations to a theoretical center line, which will be half way between the extreme surfaces of the sections as assembled and interlocked in position. This method involves the assumption that the sections when interlocked act as a unit. It is not probable that they do act in this way, but, as the method is a good one for comparative purposes, it has come into general use. It is extremely desirable, in the selection of a steel sheet-piling, that the calculations should consider the strength of the weakest member rather than that of the assemblement, because, under usual conditions of construction, the strength of the piling during driving is a most important element. One of the advantages of rolled sections consists in the fact that the section modulus of the individual member is practically the same as its theoretical modulus when interlocked in place, and elements of uncertainty are thereby eliminated from the calculations.

Vertical Strength.—When being driven, steel sheet-piling is subject to the conditions of a column loaded at both ends, one end load being the resistance of the ground, and the other being the blow of the hammer; and it is at this time particularly that such piling is subject to its most severe duty. The first consideration of strength in the design of a piling section, therefore, is its ability to withstand heavy driving without buckling or springing under the blows of the hammer; that is, the polar moment of inertia of the section and its radius of gyration are of more importance than any other of its properties. The careful engineer, therefore, will select a material with a large radius of gyration and consequent stiffness. If the piling has not the required stiffness, it will soon buckle under difficult conditions of driving, and the blow of the hammer will be spent, not in sending the piling down, but in increasing its distortion and overcoming the resultant friction between contiguous members. Too great emphasis cannot

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be laid on this feature of stiffness, and Mr. Fargo's experience, already referred to, is a case which clearly illustrates its necessity. Along with the advantage of a high radius of gyration is the desirability of a symmetrical section, in which the blow of the hammer is distributed uniformly over the top of the entire section and battering is prevented. Experience in driving shows that the symmetrical interlock channel-bar piling represents the most perfect type of fabricated section now on the market.

A large radius of gyration is desirable for perfect driving, but, at the same time, the radius of gyration of the section need not bear any definite proportion to its length, for, if the piling shows a tendency to spring in the leads, this may promptly be corrected by bolting on filler pieces across the face, after which the driving proceeds without any particular difficulty. A 35-lb. United States steel sheet-piling section with a radius of gyration of 0.83 in. has been driven in single lengths of 50 ft., and a 15-in. 44-lb. Friestedt interlocking channel-bar piling section has been driven to a length of 85 ft.; or a proportion of length to radius of gyration of 723 and 1 229, respectively. The initial difficulty, of course, is the springing of the piling in the leads; after the material enters the earth it is supported and stiffened by the earth pressure, and the blows of the hammer need but overcome the friction.

Water-tightness.—The matter of water-tightness is not of very great practical importance except in subaqueous construction. A very large proportion of the piling used is not for coffer-dam construction but for core-walls of dams, retaining walls, etc., where a minimum quantity of water needs to be kept out, and the question of water-tightness in subaqueous work is usually a function of the character of the material through which it is driven. If the river bed contains a large proportion of sand or clay, Friestedt or United States steel sheet-piles will pack themselves by carrying material down into the interlock, and in most cases Friestedt interlocking channel-bar piling is practically water-tight in itself. United States steel sheet-piling may be made water-tight with wooden packing strips, which are driven down with the piling without any particular difficulty. These packing strips, coming in contact with the water, close the joints and effectively prevent ingress. At the same time, experience with them has demonstrated that they in no way interfere with the driving of the piling, as they act rather as lubricants than otherwise. In addition to packing strips driven in the interlock, United States steel sheet-piling has been made practically water-tight by driving the edges of shingles into the space between the head and the socket, and small leaks may very readily be corrected in that way in other rolled sections now on the market. In the fabricated-beam type of piling, manufactured under the Simon patent, water-tightness is secured by puddling clay in the interlock.

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No sheet-piling manufactured is absolutely water-proof. The irregularities are such that there must necessarily be a few places in a coffer-dam where the water will penetrate, but experience indicates that the Friestedt piling is practically water-tight, the United States steel sheet-piling nearly so, and that all the other commercial forms may be made practically water-tight without serious inconvenience or special appliances. If the piling is made sufficiently tight to prevent the ingress of water absolutely, there will necessarily be difficulty in the driving, which, in the case of material to be re-used, is of much more importance than a small percentage of leakage. The use of wooden packing strips with United States steel sheet-piling has not proven to be in any way detrimental, derogatory to the use of the piling, or inconvenient, and it is a matter of history that the piling invented by Dodge did not come into extended use and was not made a commercial success until Mr. Behrend improved it by a provision for water-tightness, as well as for facility in driving. The speaker is strongly of the opinion that the proper way to provide for water-tightness when necessary is by some means which does not depend for its success on absolute accuracy in the process of manufacture. Practically 75% of the piling in the United States has been used in places where the presence of water was not serious, and where no special means were necessary to prevent its ingress. Therefore, it does not appear to be desirable, under ordinary conditions of manufacture, to prepare a type of material with a view to special conditions. Good clearance in the interlock and ease of driving are of more importance than water-tightness. Conditions arise, however, where these features are readily adapted to securing perfect water-tightness in permanent construction. In building the sea wall at Fort St. Philip, for example, it became desirable to insure the absolute water-tightness of the piling curtain-wall to resist the percolation of water from the Gulf side of the structure, and this was done by pouring cement grout down the interlock of the 12-in. 35-lb. United States steel sheet-piling, more than 1 500 tons of which were used in the construction, with results that were absolutely satisfactory and certain.

The matter of water-tightness, therefore, if mentioned in the specifications at all, should be incorporated in such a way as not to eliminate absolutely sections of which more have been sold and used than of any other type now on the market. To do so is to defeat the very end for which a specification is drawn. It may be, however, that Mr. Gifford, in making up his specifications, did not intend to do this, although the use of packing or caulking pieces is not an integral part of United States steel sheet-piling. It is true, however, that these packing strips are assembled and driven with the piling. The section, as drawn by Mr. Gifford, however, would absolutely forbid the use of

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the Simon type of fabricated-beam piling, and should, therefore, be amended to read as follows:

"Where water-tightness is required in the construction, the sections when assembled in place shall either be practically water-tight at the joints without the use of auxiliary packing or caulking pieces, or of such a character that the possibility of making them water-tight by the use of simple methods of caulking has been demonstrated by actual experience in driving."

Driving.—Under ordinary conditions, steel sheet-piling is driven with a driver of the ordinary type such as used with wooden piles, but this point cannot very well be covered by standard specifications. In light sewer work a wooden maul is usually sufficient; piling has also been driven with a portable gas hammer weighing 200 lb., as in the construction of the Colonial Avenue and Jamestown Boulevard, at Norfolk, Va.; in the construction of the Brooklyn Loop Subway, owing to lack of head-room for the use of the ordinary pile-driver, the piling was forced down with hydraulic jacks; it has also been put in place by the use of levers; and conditions will ordinarily determine what kind of equipment is desirable.

In difficult conditions of driving it will ordinarily be necessary to use a drop hammer or the pile-driving steam hammer. The advantage of a steam hammer consists in the fact that, in addition to its blow, the weight of the entire hammer is constantly on the piling. The weight of the hammer to be used should be determined, not only on the basis of the resistance of the soil, but as well on the weight of the individual piles to be driven. The hammer should be sufficiently heavy to permit the pile to absorb its share of the blow and to have a surplus force to put the piling in motion. Under general conditions, the use of a heavy hammer with a short drop is preferable, as a light hammer with a long drop has the effect of delivering a blow to the piling which will crush it rather than force it down.

The use of the water-jet for pile driving in sandy soils is sometimes of assistance. Mr. Pettit, in his paper entitled "Timbering of Excavations," already mentioned, states that he used it with success for sinking the cast-iron sheeting piles of the Assiout Barrage, Egypt. Experience with steel sheet-piling, however, would indicate that very seldom indeed is the use of the water-jet either necessary or desirable, and a number of examples have occurred in which its use was abandoned because the contractors found that the piling could be driven in the most difficult work without it, and under easy conditions it was more expensive than the ordinary method. Patents have been issued to cover the application of the water-jet to steel sheet-piling, but the speaker considers this a useless refinement and quite out of the true line of sheet-piling development. The homogeneous strength of steel is such that it need not depend on extraneous appliances for its proper

use. For the same reason it would appear that the necessity for appliances such as have been devised for placing in position types of sheet-piling composed of plain or corrugated sheets carries with it its own best condemnation. The same criticism applies to box piles or other types which require the use of pile points, cutting edges, etc. Simplicity is the first element of true economy, and a construction tool, as far as possible, should be complete in itself. Steel sheet-piling is of sufficient sharpness to cut its way through almost any material except solid rock. It has splintered and broken up boulders, and has gone through submerged timbers up to 16 in. square without difficulty. One installation, at least, is on record where a certain tonnage of this material was used in combination with wooden sheet-piling for the express purpose of penetrating submerged timbers and driftwood, and in one instance a 5 by 9-in. steel axle was encountered and broken without serious damage. Mr. Woodworth.

In spite of its advantages in this direction, however, its usefulness depends very much on the care with which it is driven. It should be driven as nearly vertical as possible, and when, by reason of unequal pressure, the piling draws ahead at the top or bottom or departs from a true alignment, such features should at once be corrected, otherwise there is danger of forcing the sections apart and of making them exceedingly difficult to withdraw. The travel ahead of the piling at the bottom may be corrected by driving wedges, nails, etc., in the top so as to secure plumbness; when the top travels ahead it should be held back with wires or ropes; and for each of these conditions a large amount of looseness and flexibility in the interlock is desirable.

Mr. Ewart stated in his patent that his cast-iron piling sections were to be assembled in position before driving. This is in no way necessary, and in one case at least the assemblement of a complete coffer-dam, before driving was commenced, nearly proved disastrous, for the structure slipped from its position and its overturn was prevented only by expeditious work. In driving a large coffer-dam, however, the proper closure is a matter of some moment, and it is desirable, when the closing corner is nearly reached, to assemble five or six short pieces of piling in position as spacers so as to get the proper alignment and distance. As the piling proceeds, these short pieces are successively pulled and long pieces driven in their place, which results in a perfect closure.

Steel sheet-piling should never be driven to refusal. If the character of the blows from the hammer indicates that some obstacle has been encountered, it is always better to let the piling stand and investigate conditions before driving any farther. It is very often necessary to leave two or three pieces sticking up above the general level, to be driven down after the coffer-dam is unwatered and exca-

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vated. Instances have occurred where the piling has been driven without regard to subterranean conditions only to find out during the process of excavation that the piling had struck a ledge of rock, separated in the interlock, and bent up like watch springs, and this was not caused by any defect in the material, but by the ignorance of those who drove it.

Piling can be driven under water or below the ends of the pile-driver leads very readily by using a follower, Fig. 16, made of a piece of piling with projecting plates riveted thereon to fit over the section below. It can also be driven to a great depth and in heavy work in spliced lengths with or without splice-plates, which are really necessary only when the material is to be withdrawn. At the Carrie Furnaces of the Carnegie Steel Company, some 400 tons or more of United States steel sheet-piling were driven to the extreme depth of 96 ft. by using three short sections driven in alternate assemblement as indicated in Fig. 16. This was driven without any splice-plates, and there was no difficulty in maintaining a perfect interlock throughout.

Whenever it is desirable to withdraw and re-use piling, a special driving cap is necessary to prevent the tops of the piles from being battered, and, as a general rule, it is desirable in view of the fact that the material encountered may make it necessary to pull and re-drive piles occasionally. These driving caps are of different patterns. They consist essentially of grooves to fit the pile-driving leads and a receptacle for a wooden block to cushion the blow of the hammer. In the driving cap patented by Luther P. Friestedt (No. 738 312) provision is also made for an additional wooden cushion to separate the two parts of the cap. This cap has a flat base, and its use is objectionable because experience has shown the desirability of having a groove in the base to hold the piling in alignment while being driven, such as is shown in the E. A. Bern patent (No. 834 866, re-issue No. 12 718). In the latter the cap was especially designed for use with United States steel sheet-piling, but has been modified to conform to other types. These cushion hoods have been made of cast steel and also of cast iron. The speaker has devised a form of driving cap, Fig. 16 (Patent No. 914 098), composed of ordinary structural material, which can be made at any fitting shop, is perfectly adequate for any ordinary driving, and commends itself by its simplicity and its comparatively low cost and weight. It also possesses features of adjustability, so that it may be used with the two plates riveted together, or separated to allow the introduction of an extra wooden cushion block, or to give additional guide bearing on the pile-driver leads.

The cost of driving and pulling depends so largely on conditions—such as the size of the job, the character of the soil, etc.—that no figures can be given which could in any way be considered general. The record, in the number of pieces driven, is held by Mr. Richard M.

Murphy, who, at Fort St. Philip, drove 1 508 tons of 12-in. 35-lb. piling 19 ft. long to a penetration of 14 ft. with a 2 800-lb. drop hammer. Although the soil was practically all silt, live oak stumps buried underground were encountered. The minimum number of piles driven per 8-hour day was 113, and the maximum 281. The labor cost of driving 413 tons of 12-in. 40-lb. piling at Carrie Furnaces, including the cost of maintenance, operation, and incidental charges, amounted to 4.1 cents per foot of penetration. It is understood that the price for driving the piling at the Black Rock lock was in the neighborhood of $3.50 per ton, and, under ordinary conditions, from $5 to $6 per ton should cover the cost of driving. Two sample records may be of interest: Mr. Woodworth.

The W. P. Carmichael Company bought some 12-in. 35-lb. piling in 1905. It was first used in building two coffer-dams on the Huron River at French Landing, Mich., and then in the construction of four coffer-dams for the Wabash River Bridge at Williamsport, Ind., where the piling was driven to a penetration of 12 ft. through sand and coarse gravel at a cost of 9.85 cents per lin. ft. for driving and pulling. The piles were driven with a small pile-driver on skids, the hammer being handled and operated by derrick and hoist. The same piling was used again for the seventh time in the construction of a coffer-dam for the Sangamon River Bridge, near Decatur, Ill., at a cost of 11.9 cents per lin. ft. for driving, and 13.72 cents per lin. ft. for pulling. The cost of driving was higher than it should have been because of using day and night gangs, the night gang averaging only about half as much work as the day gang. The cost of pulling was also high because the piles were in contact with 7 sq. ft. of concrete and were not pulled until ten months after the concrete was placed, which made it necessary to tap the piling with a pile-driving hammer to loosen it. It is also worthy of note that after the piling had been used seven times it was sold as second-hand material for $28 per ton delivered; and of the 134 pieces originally purchased only 8 were unfit for service.

In 1908 Messrs. Pihl and Miller put in an intake pipe line, 30 in. in diameter and 700 ft. long, for the blast furnace of the Wickwire Steel Company, on the Niagara River, near Buffalo, N. Y. The trench was 5 ft. wide and 12 ft. deep, and was excavated in sand, gravel, and quicksand. Enough 12-in. 35-lb. piling was bought for a trench 70 ft. in length, accommodating five lengths of 30-in. pipe. The piling was driven with a 2 800-lb. drop-hammer, and in the hardest material a jet was used. Some of the pieces were pulled and driven as often as 13 times. The sheeting cost $1 795, and the driving and pulling, $2 per ft. of trench, or about $1 500. This made a total outlay of about $3 300, as compared with an estimated outlay of $4 200, if wood had been used, and the steel piling, after its repeated re-use,

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was inventoried by the contractor at $1 400. The total saving was 48 per cent.

In the discussion of the work at Black Rock Harbor* a detailed statement is given of the results in the experimental driving tests, as far as the Lackawanna Steel Company's section is concerned; but, as this is the only series of comparative tests ever instituted, it is desirable to show the values attained. The following gives the comparative number of blows per linear foot of penetration, as reported to the manufacturers by the engineer of MacArthur Brothers Company:

Harold piling	27.60
Friestedt special section	23.38
Friestedt standard section	15.60
Lackawanna piling	14.91
12-in. 40-lb. United States section	14.72

These figures indicate in a general way the superiority of the rolled over the fabricated sections, especially of the box pile type.

At the coffer-dam for the 22d Street Bridge at Pittsburg a comparison was instituted between 15-in. 38-lb. symmetrical interlock channel-bar piling and 8 by 10-in. yellow pine piles, as follows: Steel sheet-piling was driven with a steam hammer of 5.5-ft. stroke to a penetration of 15 ft. through gravel and boulders in 4⅔ min. with 41 blows. The 8 by 10-in. pine was driven by a drop-hammer falling from 10 to 14 ft. to a penetration of 18 ft. 11 in. in 13½ min. with 97 blows.

Cutting.—In the few cases where it is absolutely necessary to cut sheet-piling to an exact level, and where time is not an important factor, hack saws may be used economically. In the construction of the foundations for the new Hoffman House, Broadway and 25th Street, New York City, in 1906, Friestedt interlocking channel-bar piling was cut by using the electric arc, the cost for current being $2.56 per ft. of piling cut and for labor 40 cents. The cost of the current was comparatively high, however, and this figure could be reduced materially. In 1908 more than 100 lin. ft. of 12-in. 35-lb. United States steel sheet-piling was cut at East 25th Street, New York City, for the Church Construction Company, by the oxy-acetylene method, in about one week's time, at an estimated cost for gas and labor, not including any allowance for depreciation or profits, of from 8 to 10 cents per lin. ft.

At Carrie Furnaces, in March, 1909, 12-in. 40-lb. piling was cut by electricity with the following results: Current used—800 amperes at 250 volts, equivalent to 200 kw. per hour, at a cost of ⅞ cent per kilowatt per hour. It required about 3 min. to cut 1 lin. ft. of piling, making the cost for current 8¾ cents per foot.

* *The Engineering Record*, April 3d, 1909.

From these results it is computed that any large quantity of piling can be cut at a cost not exceeding 12 or 13 cents per lin. ft., including current, labor, and depreciation. Mr Woodworth.

Pulling.—It has already been said that where piling is to be pulled and re-driven a special driving hood is necessary. Good driving and easy pulling go hand in hand. Careless, inaccurate driving necessarily means trouble and expense in pulling. If the piling is to be pulled within a reasonable length of time after driving, it may usually be done without difficulty with the tackle used in driving, provided care has been taken to avoid irregularities in alignment or in plumbing. Piling is usually punched with two holes for pulling. It is desirable to have two holes in order to secure an additional purchase if the piling sticks in the interlock. Piling has also been pulled by a wooden lever, with a tripod and horse, and by the cableways used in handling the material on the job. A special apparatus for pulling has been designed by Curtis and Company, of St. Louis, Fig. 16. It is based on the use of a toggle joint, and has given very satisfactory results; when this is used, pulling holes are not necessary. In connection with sinking the cast-iron sheet-piles at the Assiout Barrage, Egypt, Mr. Pettit reports that they were very often difficult to draw, and he found powerful hydraulic jacks much more satisfactory for starting the pile, and certainly safer than tackle, which, however, might be used to advantage when the pile began to move. The jacks should be used in pairs, one on each side of the pile to be drawn. This method has been advocated quite frequently in connection with steel sheet-piling also, but, as far as the speaker is aware, the suggestion has never been carried out, as it has been found practicable to accomplish the desired results with other means, and usually, if the piling refuses to come out, it may be started by light blows of the pile-driving hammer to dislodge any rust which may have accumulated and to remove the earth and water pressure. The difficulty consists always in pulling the first pile; when that comes out the others usually follow, and it very often happens that five or six come out at once. In the case of material which has to remain in place for considerable time, pulling may be facilitated by the lubrication of the joints with graphite, grease, or other lubricant, which will prevent corrosion; this method has even been used on temporary installations.

A word of caution may be given here in regard to the use of concrete. Concrete and steel bond together so tightly that it is absolutely necessary that the steel and the concrete should not come in contact. Tar-paper may be used to prevent this, but light wooden sheeting boards are more desirable. It is needlesss to say that steel sheet-piling against which any large mass of concrete has set cannot ordinarily be pulled, and instances have occurred where the attempt to do this

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has simply resulted in breaking out the holes in the piling and destroying the metal.

Specifications.—It is very true that there is no satisfactory method in general use at present for specifying the requirements of steel sheet-piling. The difficulty in most cases consists in the fact that steel sheet-piling is a patented article, and the types of it do not conform to any uniform system of construction, as is the case with standard beams and channels; consequently, the engineer who wishes to draw a specification in such a manner as to permit full and free competition is at a loss how to proceed. If he were to specify a certain type of piling, the contractors would naturally understand that that type was to be furnished, even though it were expressly stated that some other form of piling of equivalent strength might be substituted. This, however, is merely a technical point, and really does not work any greater hardship on the manufacturers of the piling whose particular type is not designated than is done in the case of specifications of structural material which refer to some manufacturer's handbook as a standard. It does not seem necessary to differentiate between steel sheet-piling and standard rolled products, as far as the elements of strength, stiffness, water-tightness, etc., are concerned, because the manufacturers of established types of interlocking steel sheet-piling publish pamphlets giving the properties of the sections, with other data sufficient for the guidance of the engineer when he prepares his designs calling for this commodity.

The method of designating steel sheet-piling by its width and weight per square foot was introduced by Mr. Luther P. Friestedt, and has proven to be entirely satisfactory, from the standpoint of both the manufacturer and the user; its advantages are that the contractor knows at once how many pieces will be necessary for any particular length of wall, and, having the length of the wall and the length of the piling, he can readily obtain the number of square feet and the weight. This practice, in the ultimate analysis, is based on experience, and is strictly in line with what is done in the sale of structural material generally, except that the weight per square foot is substituted for the weight per linear foot, and that for the very good reason that the number of square feet to be driven is one of the first things the contractor needs to know in making up his estimates. In rolled sections the weight per square foot can easily be determined from the weight per linear foot, but in fabricated sections, built up from beams and channels, as in the Jackson type, channels and Z-bars, as in the interlocking channel-bar piling, and plates and locking devices, as in the spring lock steel piling and the Wemlinger steel piling, the calculations are not so simple, and it is desirable that the computations be worked out ready for use; and for this there seems to be no fairer basis than by the weight per square foot.

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Quality of Material.—The steel generally used in the manufacture of steel sheet-piling conforms to the specifications of the American Association of Steel Manufacturers, for structural steel for buildings, with an ultimate tensile strength of from 60 000 to 70 000 lb. per sq. in., an elastic limit of not less than half the ultimate strength, and a percentage of elongation $= \frac{1\,400\,000}{\text{ultimate strength}}$. This corresponds to a carbon content of 0.18 to 0.22; manganese, 0.40 to 0.50; and phosphorus, 0.04 to 0.010, according to whether the steel is made by the open-hearth or by the Bessemer process.

Experience demonstrates that the carbon content is a question meriting consideration in specifications for sheet-piling steel. In some cases it is advantageous that the carbon content of the steel be comparatively high, having effect principally in the strength of the interlock. Ordinarily, this is not required in any large measure, but, in such few cases as may occur, it appears desirable that the specifications for that particular work should include, not only the specification for tensile strength, but the carbon content as well. Care should be taken, however, not to increase the carbon content unduly as thereby also the brittleness of the material and the danger of splitting under the blows of the hammer are increased.

Unit Strains.—Inasmuch as, in a lateral direction, piling is subject to the laws of flexure, it is very plainly apparent that specifications should conform to the established practice in building construction, and that a safe working strain may very justly be taken at 16 000 lb. per sq. in., which corresponds roughly to an elastic limit of about 36 000 lb. In the case of a coffer-dam, it is apparent that a rise in the water would not last any great length of time, and it appears reasonable that the working strains in temporary construction could be somewhat increased. If, however, the coffer-dam was calculated on a 16 000-lb. basis, to resist steady water pressure, it is likely that under flood conditions, with higher loads, swift current, floating débris, etc., the piling might be required to sustain a much higher working strain, the effects of which are not reducible to calculation. In the speaker's judgment, therefore, nothing higher than 16 000 lb. should be used as a basis of calculation.

Strength.—The question of the section modulus per foot when interlocked in place depends very largely on the bracing, but the same procedure ought to apply for temporary and for permanent work. The section moduli given by Mr. Gifford are theoretical in value, and are no doubt put forward tentatively. They do not conform to results which have been attained in good practice, and the extended application of the proposed specifications would work to the detriment of forms of steel sheet-piling which have been in extended use for a number of years with entire satisfaction. For example, 6-in. 11-lb.

Mr. Woodworth.

United States steel sheet-piling could only be used, according to Mr. Gifford's specifications, in lengths of 10 ft. or less, whereas this section has been driven in lengths of 25 ft. The 12-in. 35-lb., and 12-in. 40-lb. sections could not be used in lengths of more than 25 ft., whereas these sections have been driven satisfactorily in single pieces up to 50 ft., and in spliced lengths up to 96 ft. There seems to be no more reason why a specification for steel sheet-piling should go into the question of section modulus per foot than that the same property should be specified in the case of structural steel for buildings. The section modulus is a mathematical expression for the transverse efficiency of a section, and therefore it should be calculated, not on a foot basis, but on a basis which will represent adequately the material of which the piling is composed. Manifestly, when the working widths of the sections are greater or less than 12 in., the reduction of these values to a 12-in. basis is an arbitrary procedure, and is only justified by the practice of convenience. The more satisfactory way is to calculate these properties from center to center of integral sections.

The items of stiffness, water-tightness, and driving have been discussed, and a modification of Mr. Gifford's specification on water-tightness has been suggested. It need only here be reiterated that steel sheet-piling is essentially to be considered as a tool, and during driving care must be taken to protect it. The decision as to whether driving should be done by drop, steam, or compressed-air hammers, or any other method, can very safely be left to the contractor.

The subject of corrosion is not mentioned by Mr. Gifford in his specifications, and yet this must necessarily be considered, especially in permanent work. Thin sheets of metal may be used in light sewer and trench work, where economy is a large factor and where the piles do not remain in position permanently, but for permanent service such sheets must necessarily be avoided.

Where piling is used for a core-wall, in a dam subject to the deleterious action of such salts as are found in the soil, a thickness of $\frac{3}{8}$ in. should be sufficient; where it is subjected to the action of the acid-laden waters in streams carrying drainage from mining districts, $\frac{1}{2}$ in. is more advisable.

Protective coating has been a subject of careful investigation. The best way to protect the interlock is by puddling cement grout into it after the piling is assembled in place. For the exterior surfaces, experiments indicate that the very best coating is either Mexican or Dixon's silica graphite, applied at the shop on perfectly clean material, followed in the field by a coat of pure red lead and oil, mixed in the proportion of 25 or 30 lb. of red lead to 1 gal. of pure raw linseed oil, to be applied in the dry and thoroughly dried before driving.

Uses.—Mr. Gifford has touched in a general way on the subject of the uses to which steel piling may be put for temporary and for perma-

nent construction, and it might be interesting to include examples of the various classes of construction in which it has been used. To do so, however, would exploit the subject more fully than appears commensurate with the purpose of a technical discussion, as, in the last analysis, it is one of commerical development, and may safely be left to the zeal of the manufacturers of this commodity, who issue illustrated publications on new work of importance. Such a publication the speaker is passing through the press at the present time, and the various uses to which steel piling may be put are shown in the subject headings, namely: Coffer-dams, Sewers and Trenches, Locks and Dams, Retaining Walls, Circular Constructions (such as coffer-dams, retaining walls, pump-wells, and foundry curbing), Diaphragm Dams, Curtain-Walls, Sea Walls and Loading Slips, Dock Facing, Mine Shafts, and Building Caissons. Mr. Woodworth.

The distribution of 111 orders received in 1907 by one manufacturer was as follows:

For	coffer-dams	30
"	core-walls for dams	8
"	foundation work	3
"	loading slips	4
"	dock work	3
"	reservoir construction	3
"	retaining walls	5
"	sea walls	2
"	sewers and trenches	16
"	miscellaneous and unknown	37

The use of piling for coffer-dams is so common that there is no need of further comment. A word may be said, however, in reference to the diaphragm dam which has come into use with the development of the water-powers of the country. It consists essentially of a thin water-tight diaphragm in the center of an earthen embankment to take the place of the ordinary puddled core, concrete core, or masonry core-wall. The economical construction of dams of this character has been made possible by using steel sheet-piling which enables such sub-surface diaphragms to be made with a certainty not possible with wooden sheet-piling. A durable core or diaphragm is necessary with every earth dam, to prevent burrowing animals from making tunnels, and also to prevent trickling streams of water from developing into permanent channels. A diaphragm made of an imperishable material like steel sheet-piling has also a certain flexibility, fulfilling all the requirements of the ordinary puddled core, with the additional advantage of accommodating itself to slight inequalities of settlement in the dam. The elimination of excavations below the earth's surface also effects a large economy in construction.

Mr. Woodworth.

An early example of the use of steel sheet-piling is the construction of the diaphragm of the Avalon Dam of the Carlsbad Project, United States Reclamation Service, Carlsbad, N. Mex., under the supervision of B. M. Hall, M. Am. Soc. C. E.*

The general scheme for the construction of a diaphragm dam was followed by the Conrad Investment Company, Conrad, Mont., in building a dam for the Pondera Canal at Heins Coulee, Teton County, Mont., where United States steel sheet-piling was driven to form a permanent core-wall over the deepest part of the dam, as shown in Fig. 17. The piling was driven to solid rock, and above it was built cyclopean masonry.

An excellent example of an earth-filled dam, with a steel piling diaphragm below ground, capped by reinforced concrete, is the dam of the Indiana and Michigan Electric Company, at Berrien Springs, Mich.†

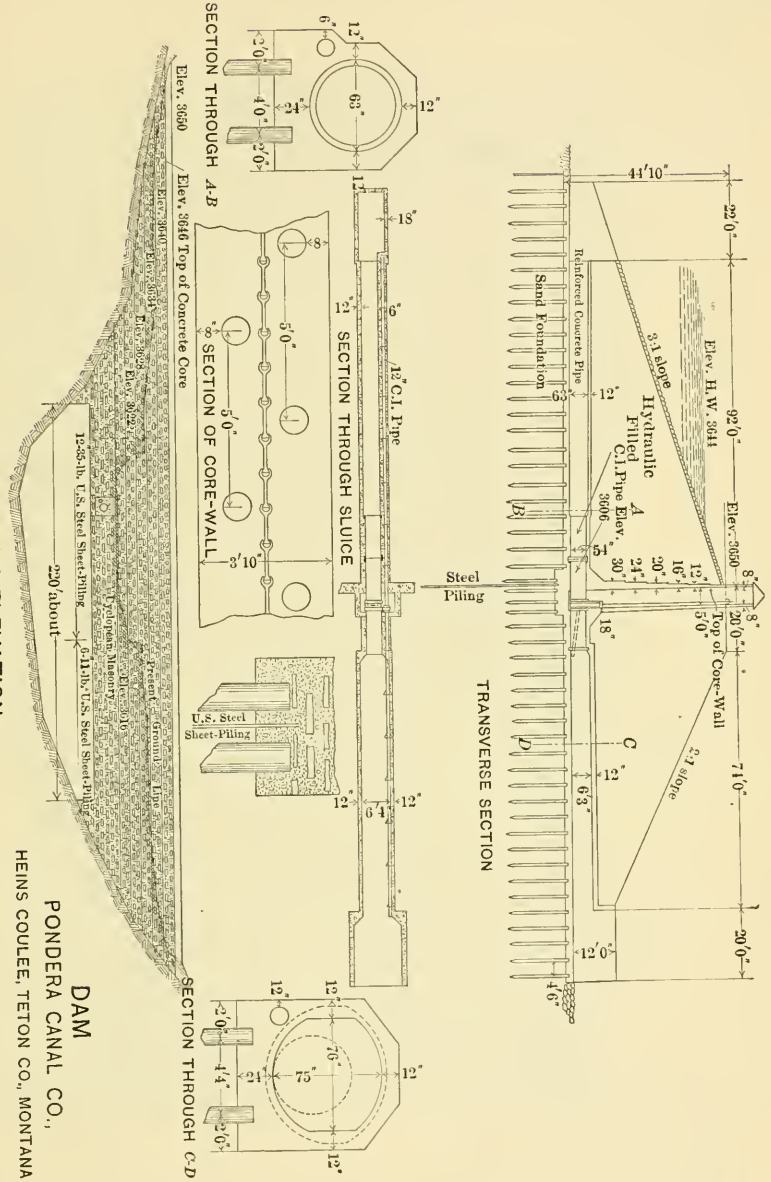
As applied to dams, the speaker distinguishes between core-walls and curtain-walls. The curtain-wall differs from the core-wall or diaphragm in that the latter is looked upon as a necessary part of the structure and is arranged for in the plans of the engineers, while the curtain-wall, though its effect is the same as the core-wall, is an after-consideration, made necessary by exigencies which arise during construction. Steel sheet-piling is excellent as a curtain-wall in preventing the destruction of old walls which have been undermined by the scouring action of the water below the original foundation lines. The first use is illustrated by the steel sheet-piling curtain-wall driven by the United States Government at Lock and Dam No. 1, on the Mississippi River at Minnehaha, Minn., and is shown in Fig. 18. The construction of the lock walls was undertaken by the use of the standard wooden sheet-piling coffer-dam. The soil in the river bottom is composed of sand and gravel filled with fragments of limestone which prevented the driving of the wooden sheet-piling to a sufficient depth to provide water-tight walls. The current in the river at this point is very swift, and the seepage at the upper end of the coffer-dam was so heavy that there was considerable difficulty in carrying on the work successfully. After several months' contention against the heavy inflow of water through the upper side of the coffer-dam, the engineers decided to make an experimental installation of United States steel sheet-piling, and 617 pieces of 12-in. 35-lb. piling were driven in lengths of 12, 18, and 24 ft., at a cost of 7.4 cents per lin. ft. of penetration. The results were entirely satisfactory in the prevention of the underflow and in the construction of the lock and dam.

The second use is illustrated in the reconstruction of Dams Nos. 2 and 3, on the Allegheny River. During the floods of 1907 the

* *Engineering News*, February 6th, 1908, pp. 145 and 147.

† *The Engineering Record*, December 26th, 1908, p. 728.

Mr. Woodworth.



DAM
PONDERA CANAL CO.,
HEINS COULEE, TETON CO., MONTANA

FIG. 17.

Mr. Wood-worth.

wooden dams were undermined, and at Dam No. 3 the banks were also eroded and swept away, and both structures were seriously crippled, not only as concerned the dams themselves, but also the wing walls, etc. In the reconstruction of these dams, 12-in. 40-lb.

LOCK AND DAM NO. 1 MISSISSIPPI RIVER
CUT-OFF WALL
of
12″35-lb. United States Steel Sheet-Piling

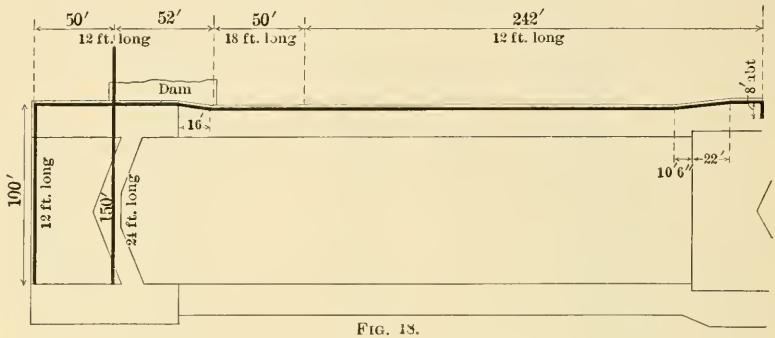


FIG. 18.

PUMP WELL PALMETTO PHOSPHATE CO.

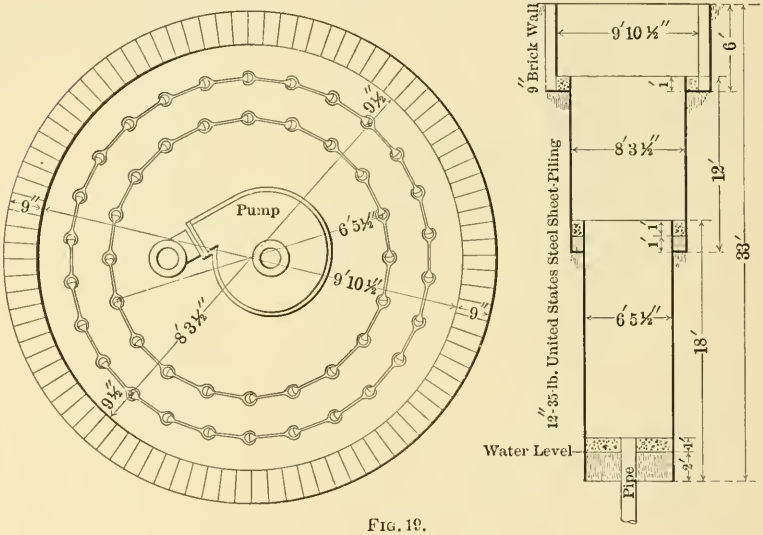
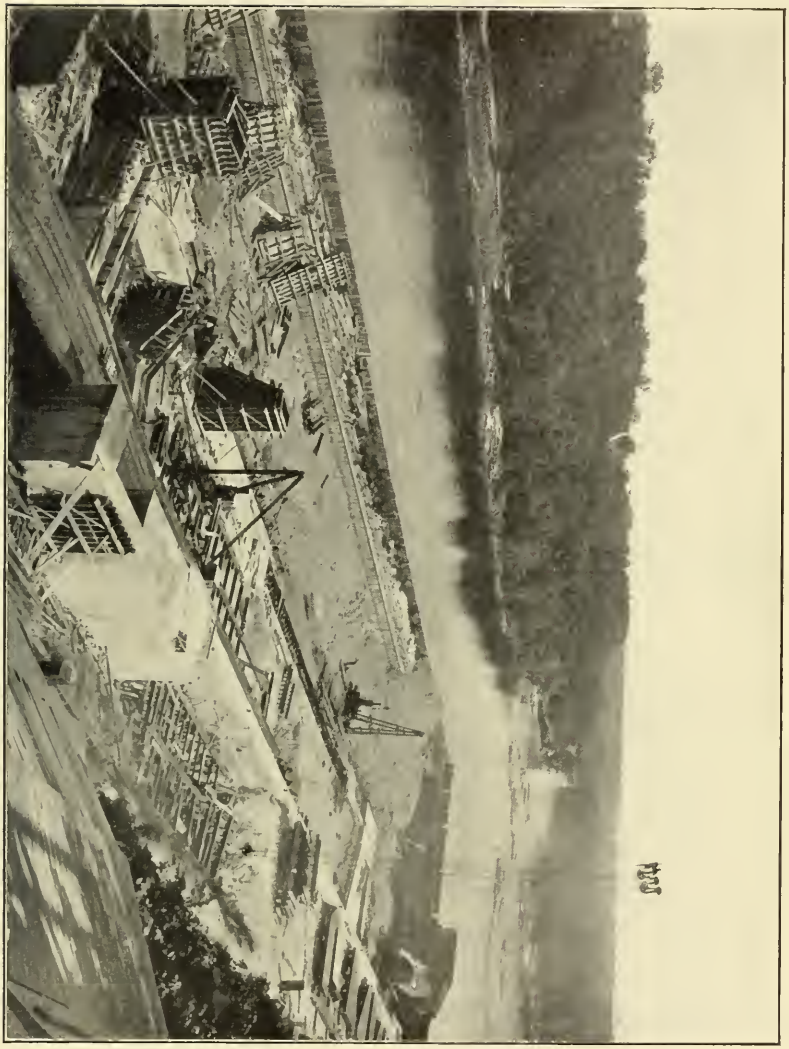


FIG. 19.

piling was driven along the up-stream face of the dams and along the river side of the wing walls, and this prevented underscouring most effectively, and made the structure practically perfect. The piling was driven in 45-ft. lengths, by steam hammers, through sand, gravel,



LOCK AND DAM No. 1, MISSISSIPPI RIVER, MINNEHAHA, MINN. CURTAIN-WALL OF STEEL SHEET-PILING.

and boulders in the river bed, eliminating the necessity for building coffer-dams and excavating to rock. Mr. Woodworth.

A very interesting use of steel piling in dam construction may be seen on the Raisin River at Deerfield, Mich., where it forms, not only the core-wall but the entire dam. Mr. C. P. Schroeder has the distinction of being the first to build a dam entirely of steel sheet-piling. The river had caused Mr. Schroeder and his predecessors much trouble and expense, owing to the percolation of underground water through the earth-filled wooden dam, so he decided to make both core and dam of piling. This was quickly and effectively driven, and without concrete reinforcement, or any other save ordinary timber wales and bracing, has withstood the floods and ice crush of two seasons. At this dam an electric power plant, having capacity of 200 or 300 h.p., drives a flour mill and lights the Village of Deerfield.

Another very interesting use of steel piling is for the construction of pump-wells, a typical example of which is shown in Fig. 19, which illustrates a well at Palmetto, Fla., for the Palmetto Phosphate Company. It is based on the idea that if sheet-piling can be made sufficiently tight to keep water out, it can also be used to keep water in. United States steel sheet-piling is peculiarly well adapted to construction of this kind.

L. R. Gifford, Assoc. M. Am. Soc. C. E. (by letter).—Two points of considerable importance which are likely to arise in connection with the use of any type of steel sheeting or sheet-piling have been mentioned in the discussions; these are the durability for permanent work, and the design of the interlocking joint. Mr. Gifford.

Consideration of the question of durability practically opens up the entire subject of corrosion under varying conditions, regarding which all would like to have more definite information.

Corrosion—by which is meant the effect produced on metals by the combined action of water and oxygen—has generally been considered to be a chemical process, although the latest theories state that all corrosion is electro-chemical, rather than purely chemical in character.*

Electro-chemical action, however, must not be confused with electrolysis, so destructive to iron or steel structures, caused by return currents from extraneous sources.

In those cases where steel is deeply embedded in the earth and the supply of free oxygen is limited, as it must be under these conditions, there is good reason to believe that, aside from the slight initial corrosion, there is little, if any, rusting, and this conclusion seems to be in accord with the observed facts. There is no doubt that the chemical composition of the steel influences the corrosion, and the character of the soil in which it is placed is also a factor.

* Paper by Allerton S. Cushman, "Electrolysis and Corrosion," *Proceedings*, Am. Soc. for Testing Materials, Vol. VIII, p. 238 *et seq.*

Mr. Gifford. Near the surface, and for this reason subjected to varying conditions of moisture, it is not unreasonable to expect that a more or less rapid corrosion will take place.

Members of the Society will no doubt recall that the question of the durability of iron and steel in foundations was one of the topics discussed at the Annual Convention of the Society held in 1907, in the City of Mexico, and was particularly referred to in the remarks of J. F. O'Rourke, M. Am. Soc. C. E.,* and Senores Pablo Solís and Octavio Guzmán,† all of whom explained at some length their reasons for believing that steel in foundations would last indefinitely.

Passing now to the design of the interlocking joint, the first question to be asked is, what office does the joint perform? and the second, to what stresses is it subjected?

Consider, for the moment, the simplest form of piling, which consists of planks driven edge to edge. If an excavation is made on one side of this planking, the pressure will force it more or less out of line, assuming that the bracing gives sufficiently to allow this, showing clearly a tendency to shearing at the joints, to which it offers no resistance.

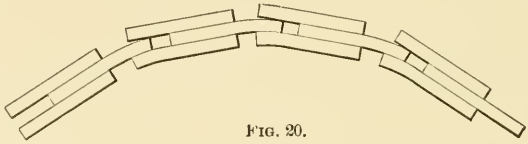


FIG. 20.

The next step in the use of timber piling is to provide the edges of the planks with tongues and grooves, or their equivalent. This resists the shearing stresses and incidentally serves as a guide, but offers no resistance to tensional stresses. When a wall of piling of this type is forced out of line, the joints will be found to have opened, about as shown in Fig. 20.

An inspection of Fig. 20 will show that, in addition to the shearing, there is a bending stress at the joint; or, to state it differently, the tendency is to pry the joint apart.

In a steel piling with an interlocking joint, it is possible to provide all the elements of strength supplied in the timber piling with tongues and grooves, and the additional one of tension.

It is clear that the first office of the joint is to resist the tendency of one pile to be forced out of line more than the adjacent pile, which, as explained above, develops a shearing action. With an interlocking joint, the result of forcing the piling out of line is to set up in the joint a combination of shearing tension and bending. This may be demonstrated in another way by a consideration of the following:

* *Proceedings*, Vol. XXXIII, No. 6.

† *Proceedings*, Vol. XXXIII, No. 7.

Assume a line of piling between the points, *A* and *B*, Fig. 21, driven in perfect alignment. If the piling is forced out of line, it will tend to assume a position such as *A C B*, the greater distance between *A* and *B* on the line, *A C B*, being secured by the clearance in the joints. If the joints do not fail, the resulting stress must be a combination of shearing, direct tension, and bending across the joints. Mr. Gifford.

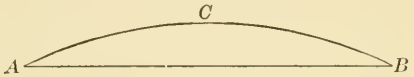


FIG. 21.

It is not difficult to see, from the foregoing, that a joint which has a high resistance to direct tension, might fail by reason of the cross-bending or the shearing.

It would be entirely practicable to design a joint, somewhat like Fig. 22, which would develop 100% of the strength of the web of the piles in direct tension, but would be entirely deficient in resisting bending and shearing stresses, and would not make a satisfactory piling.

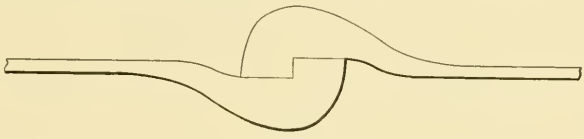


FIG. 22.

One should not overlook the fact that the bottom of the line of piling, which would be below the excavation, would be held by the earth approximately in the line, *A B*, while the top would be forced over to the line, *A C B*.

The inference to be drawn from this is that the stress in the joints is, after all, simply the result of a lack of lateral strength in the piling. If the piling possessed sufficient strength to resist the pressure properly, it would retain its alignment, and the joints would not be called on to do any of the work.

The results of tensional tests of joints, given by Mr. Meem and Mr. Woodworth, are interesting, and show clearly that in those special cases where direct tensional stresses have to be provided for, the joint alone cannot be depended on, and an auxiliary construction of proper design should always be used. The tests give no information whatever regarding the resistance to a combination of tension, cross-bending, and shearing, which must be provided for in the majority of cases. Mr. Woodworth, however, notes the fact that, with the fabricated sections tested, the slightest deviation from a straight line in the application of the pull on the testing machine resulted in transverse bending moments which crippled them and decreased their resistance to direct tension.

Mr. Conkling calls attention to the fact that the joints are subjected to both tensional and transverse stresses when the piling is

Mr. Gifford. forced out of line, and suggests at the same time that the specifications include a requirement for tensional strength, neglecting entirely the transverse strength, which is certainly equally important.

On account of the fact that the bending and shearing is such a large factor in the stress at the joint, in the general case, any figures obtained from tests in direct tension are extremely misleading, and it was for this reason that, after careful consideration of the subject, no requirements for that feature were introduced in the proposed specifications.

There is, at the present time, a large job on which the requirement of high tensional resistance of the joint was made a determining factor in the selection of the type of piling to be used. The basis of the design, in this instance, was an outer and an inner wall of piling, with connecting cross-walls forming a series of pockets to be filled with clay, the idea being that the walls of the coffer-dam, which would be subjected to the pressure of the clay filling, would be held in position by the cross-walls. This result was only partly accomplished, as the piling used was so defective in lateral strength that the sides between the cross-wall ties are badly bulged and seem to be in danger of failure by reason of the joints opening up on account of the resulting bending stresses.

This particular job could certainly be studied with a great deal of profit by anyone having occasion to design large coffer-dams of steel piling.

Specifications.

Material.—Mr. Woodworth suggests the advantage, in certain cases, of including a requirement for carbon in the specifications for material. The writer, however, believes that if the material meets the American Association of Steel Manufacturers' specifications for buildings, which require an ultimate strength of from 60 000 to 70 000 lb. per sq. in., that it is not necessary to introduce a requirement for carbon content.

Unit Strains.—There seems to be some difference of opinion regarding the proper unit strains. Mr. Conkling and Mr. Woodworth suggest a limit of 16 000 lb. per sq. in., under all conditions, while Mr. Fowler considers that it would be safe to use 24 000 lb. per sq. in. for temporary work and 20 000 lb. per sq. in. for permanent work. The writer believes that it is logical to use a higher unit stress on temporary work, for the reason that, generally, the construction is under observation at all times, and if there are indications that the piling is not standing up to the work properly, additional bracing can be introduced.

Strength.—Engineers who handle structural steelwork are accustomed to the use of the section modulus of rolled shapes as tabulated by the various manufacturers, and the writer believes that all the

manufacturers of steel piling should publish this property for their piling, as it simplifies calculations for strength very much. Mr. Gifford.

On account of the varying widths of different types of piling, practically the only way to compare their strengths is to compute the section modulus for a single piece, after assembling, and then reduce it arbitrarily to a basis of 1 ft. in width of assembled piling.

The writer introduced the tabulation of the section moduli required for permanent and temporary construction corresponding to the fiber stresses specified under "Unit Strains," in order to simplify matters in those cases where special calculations were not made, and this is, as stated, a minimum requirement.

As a matter of interest, the writer has computed, on the basis of a fiber stress of 1 000 lb. per sq. in., the thickness of timber corresponding to the lengths specified. These results are as follows:

Lengths of	10 ft. or less					$1\frac{1}{2}$	in. thick.
"	from 10 "	to 15 ft				$2\frac{1}{2}$	" "
"	" 15 "	" 20 "				4	" "
"	" 20 "	" 25 "				$5\frac{1}{2}$	" "
"	" 25 "	" 30 "				$7\frac{1}{2}$	" "
"	" 30 "	" 35 "				$9\frac{1}{4}$	" "

In making this comparison, no attention has been paid to the commercial thicknesses of timber, and it should be noted that the lengths which can readily be procured would not exceed 20 ft.

Stiffness and Water-Tightness.—The relative importance of water-tightness and stiffness is, to a certain extent, variable, depending on the character of the work. Hard driving requires a stiff pile, and, with water-bearing soil and quicksand, a tight joint is necessary.

Mr. Woodworth objects to the writer's specification for water-tightness, while Mr. Conkling expresses agreement with the manner in which this requirement is stated. The writer doubts the efficacy of any attempt to caulk a joint by using small wooden splines driven into the joint after it is in place, or of forcing cement into the joints. The joints are naturally packed full of earth when the piling is driven, and it is practically impossible, either to clean out the joint and fill it up again, or to force anything into it. If the joint is designed so that the water in passing through is obliged to make several turns, the pressure is necessarily reduced, and, in almost any soil, the opening will soon become silted up so that no water can pass.

Driving.—The writer considers that a pile-driving hammer, operated by steam or compressed air, which strikes rapid blows at short intervals, keeps the pile moving, batters it less, and is altogether much more satisfactory than any other.

Generally.—The comparative advantage of flexible or rigid joints is an open question, and, for this reason, the proposed specification does not refer to this feature. It should be noted, however, that with

Mr. Gifford. a flexible joint, it is necessary to use more care in driving in order to keep the piling in good alignment, or to use guide piles, which add materially to the expense.

Mr. Conkling, in referring to the writer's formula for bending, apparently overlooks the fact that the center of pressure, which is at one-third of the height from the bottom, does not coincide with the point of maximum bending, that is, the distance, x, in the demonstration.

Mr. Higgins' experience shows clearly the necessity for lateral strength in steel piling, which the writer has made the first requirement in the proposed specifications. A case somewhat similar to that cited by Mr. Higgins has been called to the writer's notice. In constructing the foundations for a large building, the column footings were built in circular wells formed of steel piling, which was used instead of caissons. The particular type of piling used, however, was deficient in lateral strength; the first pile driven deflected after entering the ground, and, notwithstanding the fact that the portion out of the ground was held in the leads of the pile-driver, it could not be driven vertically. The result was that the wall of piling, following the direction of the first pile, was inclined at a considerable angle, and, as a consequence, the column footing was restricted to a smaller size than had been contemplated.

It seems hardly necessary to add that, the stronger the piling, the less the bracing required, and the less the working space will be restricted, although this latter important feature seems to be frequently overlooked.

The writer appreciates fully that the pressure on sheet-piling in place may be greatly in excess of the hydrostatic pressure, as pointed out by Mr. Fowler, and, for a specific case, the conditions to be met should receive careful consideration. As a basis of comparison, however, the assumption of hydrostatic pressure gives values which are sufficiently correct.

Mr. Fowler seems to be under the impression that the types of piling listed under Group 1 are superior in lateral strength to those listed under Group 3, which is not the case, as will be noted by reference to the diagrams.

The diagrams constructed by Mr. Goodrich are interesting, but inconclusive, as there are several very important factors entering into the question of cost, other than the price per pound. One of these is the amount of finished piling secured for each piece driven. Some of the sections shown on the diagram have an effective width of 6 in., while others have 14 in. Another item which varies widely is the cost of driving. Concrete piling is more expensive to drive than steel piling, and does not generally have interlocking joints. More than this, the fields of usefulness for steel and concrete sheet-piling do not overlap to any great extent.

Mr. Woodworth's historical sketch of the development of metal

sheet-piling is extremely interesting and instructive. The writer, Mr. Gifford.
however, feels obliged to question the statement that any construction of Z-bars and channels can be made the "strongest and stiffest steel sheet-piling made in the United States," as several of the other commercial sections are, or can be, made with practically unlimited strength. What is wanted, however, is the most economical section to carry the loads to be provided for under a given condition. There is no difficulty in securing the strength required, but it is necessary to consider what type will do the work at the lowest cost.

The Wemlinger corrugated type has been used much more extensively than Mr. Woodworth states.

The diagram constructed by Mr. Goodrich, although it is inconclusive, for the reasons previously stated, contradicts Mr. Woodworth's statement that the specially fabricated sections are more expensive than those of special rolled shapes.

The cost is not measured by the price per pound, or per linear foot, of the section, but by the price per square foot in place, of piling of the proper strength to do the required work; in other words, what the engineer and contractor wants is sufficient strength per square foot to be covered, without excess of material or strength.

Mr. Woodworth's statement that clearance in the interlock is indispensable for proper driving, and particularly for pulling, agrees with the writer's experience. The type of joint proposed by Mr. Skinner is believed to be a step in the wrong direction, and the advantage of six lines of contact in the joint, even if they can be secured, which is questionable, is not easily understood.

Painting piling before driving is of little or no value for protection against corrosion, as it would be, if not all scraped off in driving, at least so badly injured as to be practically useless.

All who are interested in steel sheet-piling should appreciate the fact that they are, to a large extent, pioneers in a new field of very great opportunities, and the most pressing need at the present time is a clearer understanding of the essential requirements.

One of the best ways to put the whole proposition on a sensible and proper basis, is to frame a set of specifications, which, as far as possible, will standardize the requirements and fix and determine in a rational manner the conditions to be filled by the type selected. It is impossible in any other way to eliminate the non-essential and purely imaginary advantages, which exist only in the minds of the patentees or promoters, and determine which type is most economical under a given set of conditions.

The writer, after reading carefully all the discussions presented, believes that the proposed specifications cover practically all the essential requirements, and that they are fair to all types, without favoring any particular one.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1116.

THE DESIGN OF ELEVATED TANKS AND STAND-PIPES.*

By C. W. Birch-Nord, Assoc. M. Am. Soc. C. E.

With Discussion by Messrs. Charles B. Burdick, O. E. Selby, Charles C. Hopkins, William Murray Black, J. Madison Porter, E. G. Walker, A. W. Carpenter, and C. W. Birch-Nord.

Introduction.

It is the writer's intention to submit herewith a general specification for the design of elevated tanks and stand-pipes, which he wishes adopted by the Engineeering Profession. As far as he knows, this subject has never before been treated for this purpose, and it is therefore his most sincere wish that experienced engineers in this field will offer their most severe criticisms, in order to make the final revised specification a sound guide. Attention may be called to the fact that this specification has been used by the writer for some time, and has always been applied successfully.

The writer wishes to express his obligations to A. F. Reichmann, M. Am. Soc. C. E., and Mr. J. H. Hoff, for assistance in the preparation of this paper.

General Specifications for Stand-Pipes, Tanks and Towers.

Loads.

1.—The dead load shall consist of the weight of structural and ornamental steelwork, platforms, roof construction, piping, etc.

2.—The live load considered shall be the contents of tanks, the movable load on platforms and roofs, and the wind pressure.

* Presented at the meeting of May 5th, 1909.

3.—The weight of water shall be assumed to be 63 lb. per cu. ft., and that of crude oil 56 lb. per cu. ft., 1 cu. ft. of fluid being equal to 7.48 gal.

4.—The live loads on platforms and roofs shall be taken at 30 lb. per sq. ft., or a 200-lb. concentrated load applied at any point.

5.—The wind pressure shall be assumed at 30 lb. per sq. ft., acting in any direction. The surfaces of cylindrical tanks exposed to the wind shall be calculated at two-thirds of the diameter multiplied by the height.

6.—The movable live load on platforms and roofs shall not be considered as acting together with the wind pressure.

Unit Strains.

7.—All parts of the structure shall be proportioned so that the sum of the dead and live loads shall not cause the strains to exceed those given in Table 1.

TABLE 1.

	Pounds per square inch.	
Tension in tank plates	12 000	Net area.
Tension in other parts of structure	16 000	" "
Compression	16 000	Reduced.
Shear on rivets and pins	12 000	
Shear on bolts and field rivets	9 000	
Shear in plates	10 000	Gross section.
Bearing pressure on rivets and pins	24 000	
Bearing pressure on field rivets	18 000	
Fiber strain in pins	24 000	

8.—For compression members, the permissible unit strain of 16 000 lb. shall be reduced by the formula:

$$p = 16\,000 - 70\,\frac{l}{r}$$

where p = permissible working strain in compression, in pounds per square inch;

l = length of member, from center to center of connections, in inches;

r = least radius of gyration of section, in inches;

the ratio, $\frac{l}{r}$, shall never exceed 120 for main members and 180 for struts.

9.—Stresses due to wind may be neglected if they are less than 25% of the combined dead and live loads.

10.—Unit strains in bracing and other members taking wind stresses may be increased to 20 000 lb. per sq. in., except as shown in Section 9.

11.—The pressures given in Table 2 will be permissible on foundations and bearing plates.

TABLE 2.

	Tons per square foot.
Soft clay	1
Ordinary clay	2
Dry sand and dry clay	3
Hard clay	4
Gravel and coarse sand	6
	Pounds per square inch.
Brickwork with cement mortar	200
Portland cement concrete	350
First-class sandstone	400
First-class limestone	500
First-class granite	600

Details of Construction.

12.—The plates forming the sides of cylindrical tanks shall be of different diameters, and shall be caulked from the inside. No foreign material shall be allowed when caulking.

In oil-tank work, both the inside and the outside of the tank shall be beveled for caulking.

13.—Joints for horizontal seams and for radial seams in the spherical bottoms of tanks shall preferably be lap joints.

14.—For vertical seams lap joints shall be used for $\frac{1}{4}$, $\frac{5}{16}$, and $\frac{3}{8}$-in. plates; double butt joints for $\frac{7}{16}$, $\frac{1}{2}$, $\frac{9}{16}$, $\frac{3}{4}$, and $1\frac{3}{16}$-in. plates; and triple butt joints for $\frac{7}{8}$, $\frac{15}{16}$, and 1-in. plates.

15.—Rivets, $\frac{5}{8}$ in. in diameter, shall be used for $\frac{1}{4}$ and $\frac{5}{16}$-in. plates; rivets, $\frac{3}{4}$ in. in diameter for $\frac{3}{8}$ to $\frac{5}{8}$-in. plates, inclusive; and rivets, $\frac{7}{8}$ in. in diameter, for $1\frac{1}{16}$ to 1-in. plates, inclusive.

16.—Plates more than $\frac{5}{8}$ in. thick shall be sub-punched and reamed.

17.—The minimum thickness of the plates for the cylindrical part shall be $\frac{1}{4}$ in. The thickness of the plates in spherical bottoms shall never be less than that of the lower ring in the cylindrical part of the tank.

18.—The facilities at the plant where the material is to be fabricated will be investigated before the material is ordered.

19.—All plates shall be punched before being bevel-sheared for caulking.

20.—Radial sections of spherical bottoms shall be made in dupli-

cates of the number of columns supporting the tank, and shall be reinforced at the lower parts, where holes are made for piping.

21.—When the center of the spherical bottom is above the point of connection with the cylindrical part of the tank, there shall be provided a girder at said point of connection to take the horizontal thrust. The horizontal girder may be made in connection with the balcony. This also applies where the tank is supported by inclined columns.

22.—The balcony around the tanks shall be 3 ft. wide, with a $\frac{1}{4}$-in. floor-plate, and shall have a suitable railing, 3 ft. 6 in. high.

23.—The upper parts of spherical bottom plates shall always be connected on the inside of the cylindrical section of the tank.

24.—In order to avoid eccentric loading on the tower columns, and local stresses in spherical bottoms, the connections between the columns and the sides of the tank shall be made in such a manner that the center of gravity of the column section intersects the center of connection between the spherical bottom and the sides of the tank. Enough rivets shall be provided above this intersection to transmit the total column load.

25.—If the tanks are supported on columns riveted directly to the sides, additional material must be provided in the tank plates riveted directly to the columns to take the shear. The shear may be taken by providing thicker tank plates or by reinforcement plates at the column connections, while bending moments shall be taken by upper and lower flange angles. Connections to columns shall be made in such a manner that the efficiency of the tank plates is not less than that of the vertical seams.

26.—For high towers, columns shall have a batter of 1 to 12. The height of the tower is understood to be the distance from the top of the masonry to the connection of the spherical bottom, or the flat bottom, with the cylindrical part of the tank.

27.—The bottom plates of stand-pipes shall be not less than $\frac{5}{16}$ in. thick, and shall be provided with tapped holes, $1\frac{1}{4}$ in. in diameter, with screw-plugs spaced at 4-ft. centers to allow a filling of cement on top of the masonry, while the bottom part is being erected, in order to secure the proper bearing.

28.—Near the bottom of the stand-pipe there shall be provided one 12 by 18-in. manhole of elliptical shape.

29.—Near the top of each tank and stand-pipe there shall be pro-

vided one Z-bar acting as a support for the painters' trolley, and for the stiffening of the tank. The section modulus of the same shall be not less than $\frac{D^2}{250}$, where D is equal to the diameter of the tank, in feet. If the upper part of the tank is held by the roof construction, this may be reduced.

30.—On large tanks, circular stiffening angles shall be provided in order to prevent the tank plates from buckling during windstorms. The distance between the angles shall be determined by the following formula:

$$d = \sqrt{t}\,\frac{900}{D}$$

where d = approximate distance between angles, in feet;
t = thickness of tank plates, in inches;
D = diameter of tank, in feet.

31.—The top of the tank will generally be covered with a conical roof of thin plates; and the pitch shall be 1 to 6. For tanks up to 22 ft. in diameter, the roof plates will be assumed to be self-supporting. If the diameter of the tank exceeds 22 ft., angle rafters shall be used to support the roof plates.

Plates of the following thicknesses will be assumed as self-supporting for various diameters:

$\frac{3}{32}$-in. plate, up to a diameter of 18 ft. 0 in.
$\frac{1}{8}$-in plate, up to a diameter of 20 ft. 0 in.
$\frac{3}{16}$-in. plate, up to a diameter of 22 ft. 0 in.

Rivets in the roof plates shall be from $\frac{1}{4}$ to $\frac{5}{16}$ in. in diameter, and shall be driven cold. These rivets need not be headed with a button set.

32.—A trap-door, 2 ft. square, shall be provided in the roof plate. Near the top of the higher tanks, a platform with a railing shall be provided, for the safety of the men operating the trap-door.

33.—An ornamental finial shall be provided at the top of the roof.

34.—A ladder, 1 ft. 3 in. wide, shall be provided from a point about 8 ft. above the foundation to the top of the tank, and also one on the inside of the tank. Each ladder shall be made of two $2\frac{1}{2}$ by $\frac{3}{8}$-in. bars with $\frac{3}{4}$-in. rungs. On large, high tanks, 30 ft. or more in diameter, a walk shall be provided from the column nearest the ladder to the expansion joint on the inlet pipe.

35.—In designing tanks, 6 in. additional height shall be allowed for over-run.

36.—The bracing in the towers shall be adjustable.

37.—The size of the anchor-bolts shall be determined by the uplift when the tank or stand-pipe is empty. The unit strains in the anchor-bolts shall not exceed 15 000 lb. per sq. in., and the minimum section shall be limited to a diameter of 1¼ in.

38.—The concrete shall be assumed to have a weight of 140 lb. per cu. ft., and shall be sufficient in quantity to take the uplift.

39.—Any parts of the tank, stand-pipe, or tower, in which difficulties may arise in field riveting, shall be assembled in the shop, and marked properly before shipment.

40.—The structural material shall conform to the "General Specifications for Steel Railroad Bridges" by the American Railway Engineering and Maintenance of Way Association.

41.—The workmanship shall be in accordance with the Manufacturers' Standard Specifications of February 6th, 1903.

42.—Before leaving the shop, all work shall be painted with one coat of approved paint, excepting the laps in contact on the tankwork. All parts which will be inaccessible after erection shall be well painted. After erection, the structure shall be covered with one coat of the same paint.

43.—Three-ply frost-proof casing shall be provided, if necessary, around the inlet pipe. This casing shall be composed of two layers of 1 by 2½-in. lumber, and each layer shall be covered with tar paper, and one outside layer of ⅞ by 2½-in. dressed and matched flooring. The lumber shall be in lengths of about 12 ft. A 1-in. air space shall be provided between the layers of lumber, and wooden rings or separators shall be nailed to them every 3 ft. The frost casing may be made square or cylindrical.

DISCUSSION

Mr. Burdick. CHARLES B. BURDICK, ASSOC. M. AM. SOC. C. E. (by letter).—The author is to be commended for presenting in concise form the requirements for the design of elevated tanks and stand-pipes. The value of the paper, however, would be greatly increased by taking up the items separately and giving the reasons which led to the conclusions.

In regard to Section 7, on Unit Strains, apparently no especial consideration is given to the action of ice, which is generally regarded as producing an important stress. In a measure, this is allowed for in the moderate permissible tensile stresses in plates, and also in the requirement for minimum thickness of plates, which gives increased strength at the top of the tank where the ice action is probably at a maximum.

It seems to the writer, however, that the matter of climate should be given consideration in fixing allowable unit stresses. Good design will not permit the same strains in such extremes of climate as Florida and Minnesota. It is considered good practice in the vicinity of Chicago and northward to limit the plate unit stress to 10 000 lb. per sq. in. of net section for tanks in which the plate is directly exposed to the weather. It is believed, however, that proper design permits greater unit stresses where the steel is enclosed or encased by a protective covering which eliminates or reduces to a minimum the formation of ice.

Mr Selby. O. E. SELBY, JUN. AM. SOC. C. E. (by letter).—This paper presents a desirable addition to the list of standard engineering specifications. Heretofore, specifications for structures included within the scope of the paper have been, to a great extent, the output of designers employed by manufacturers, and have shown the effects of the latters' bias.

If this discussion seems to be largely in the line of pointing out shortcomings in the author's specifications, it is not done in any spirit of criticism, but with a desire to see the specifications properly amplified and completed before they pass into a form which may be adopted as a standard. It is the writer's view that a technical specification should be something more than a mere check on the contractor; it should be a manual of design, complete enough to be a guide for the designer, whether he be employed by the purchaser or manufacturer, and should be so explicit and unambiguous as to permit of little discretion on the part of the designer, to the end that two independent designers working from it will produce substantially the same results.

The specifications seem to start with the assumption that the general dimensions of the structure are fixed. This should not be. For any given capacity and pressure there are certain economical

ratios between height and diameter for elevated tanks, and there are other ratios for stand-pipes. Something relating to these rules of proportion should be included. Mr. Selby.

The specifications cover only stand-pipes and elevated tanks with hemispherical or flat bottoms supported on steel towers. One important form of elevated tank is ignored, that is, the tank with a semi-elliptical bottom and a small stand-pipe extending from the bottom to the ground, which serves both as a partial support for the tank and as a frost-proof inlet. This form is used largely for railroad water-station tanks, and the features which are peculiar to it should be included in this manual of design.

It is convenient to assume the weight of water at 62.5 lb. per cu. ft., because this makes convenient figures for calculation, namely, $8\frac{1}{3}$ lb. per gal. and $7\frac{1}{2}$ gal. per cu. ft. The use of two-thirds of the exposed area for computing wind pressure on cylindrical tanks is better practice than the use of one-half, as is done in many specifications. This ratio should be extended also to conical surfaces.

Table 1 allows a tension of only 12 000 lb. per sq. in. in tank plates, while a tension of 16 000 lb. per sq. in. is allowed in other parts of the structure. This is in accordance with common practice, and gives good results, although there is no apparent justification for the reduced unit stress. The tank plates are just as strong as structural shapes, and the loads coming upon them are just as capable of exact calculation. Of course, the ordinary reason for using a reduced unit stress is to provide extra section to cover corrosion and other forms of deterioration. It would seem more rational to provide for this by an arbitrary addition to the thickness computed from the static pressure and net section. In fact, the writer has found it desirable and not any great hardship to specify an additional thickness of $\frac{1}{16}$ in. for tanks designed for a unit stress of 12 000 lb.

The allowable shear on rivets is given as 12 000 lb., with no stipulation that there shall be any reduction of this unit stress for rivets in tank plates. If the tank plates are designed for 12 000 lb. per sq. in. in tension, the rivets certainly ought to be designed for proportionately low unit stresses in shear and bearing. The allowed shear on field rivets and bolts is lower than that usually permitted. It is customary to prescribe that the number of field rivets shall be increased to 25% more than the number required for shop-driven rivets. On this basis the shear in field rivets would be 9 600 lb. per sq. in. instead of 9 000 lb.

No information is given in the specifications as to the efficiency of riveted joints. This is an important feature in designing tanks and boilers, as the computations, usually, are made directly on the basis of the efficiency of the joint, rather than by the more indirect process of computing the net section. It would be desirable to include a table showing the computed efficiencies of single- and double-lapped

Mr. Selby. joints and single-, double-, and triple-riveted butt joints for various thicknesses of plates and diameters of rivets. Such tables are used by every manufacturer, and are published by some of them.

The use of the percentage of efficiency in the joint results in a simple formula for determining the thickness of plates in tanks subjected to hydrostatic pressure. Thus, if D = the diameter of the tank, in feet, H = the height, in feet, from the point considered to the surface of the water; the pressure, in pounds per square inch = 0.434 H. The tension in the plate for 1 in. in height = t = 2.6 D H. The required net area of the plate for 1 in. in height = $A = t \div f$, f being the unit stress, in pounds per square inch of net section. For f = 13 000, A = 2.6 D $H \div$ 13 000 = 0.0002 D H. For an efficiency of two-thirds in the riveted joint, the gross area in 1 in. of height = the thickness of the plate, in inches = $A \div \frac{2}{3}$ = 0.0003 D H. To this should be added the additional thickness of $\frac{1}{16}$ in. already referred to. This formula, thickness of plate = 0.0003 D H, makes a convenient and rapid method of determining the thickness of tank plates. For a unit stress in tension of 12 000 lb. the same formula results, if an efficiency of 72% is assumed.

It is customary to design on a basis of efficiency of at least 66%, and that would rule out all single-riveted lap joints. Section 14 specifies lap joints for vertical seams in plates $\frac{3}{8}$ in. thick and less, but does not specify whether they shall be single or double. They should be specified as double-riveted, with the possible exception of $\frac{1}{4}$-in. plates, in which the full strength of the plate is not developed. Double-riveted butt joints with the rivet diameters specified in Section 15, will secure an efficiency of at least 70% up to and including a thickness of $\frac{3}{4}$ in. For that reason it would seem desirable to design for an efficiency of 70%, and specify triple-riveted butt joints for plates having a thickness of $\frac{13}{16}$ in. or more.

The unit stress in compression should be limited to a maximum of 15 000 lb. for short columns.

Section 10 is ambiguous in that it allows unit stresses of 20 000 lb. in bracing, without specifying whether the unit stress referred to is for tension, compression, shear, or bearing. It gives a desirable addition to the bracing—which otherwise may be designed too light—to assume an arbitrary initial stress in all bracing members of 5 000 or 10 000 lb.

Section 12, specifying that plates forming the sides of cylindrical tanks shall be of different diameters, is not explicit. Of course, it means that the inside diameter of one plate shall be the same as the outside diameter of the next one.

In Section 13 it is not clear just what is meant by radial seams in a spherical bottom.

Section 16 specifies that plates more than $\frac{5}{8}$ in. thick shall be sub-

punched and reamed, but does not specify the diameter of the punched hole and the amount to be removed by reaming. Mr. Selby.

Section 29 gives a rule for proportioning the stiffening member around the top of the tank, and specifies that the section modulus may be reduced under certain conditions, but does not specify definitely to what extent it may be reduced.

Section 35 allows an additional height of 6 in. for over-run. This is not clear. Presumably the meaning is that 6 in. in height shall be added to that required for the specified capacity in gallons.

Section 36 specifies that the bracing in towers shall be adjustable. Certainly riveted bracing for towers is better practice, although adjustable bracing may be allowable, on the score of economy, and the riveted bracing should not be excluded.

Section 37 specifies unit stresses in the anchor-bolts not exceeding 15 000 lb. per sq. in. Presumably, this refers to unit tensile strength, but it is not explicit. There is no specification covering the excess of the area at the root of the thread, and no specification which would produce good details in the design of the anchorage connections. Too many anchor-bolts are connected simply through the base plate of the column without provision for developing properly the full strength of the bolt, and this should be covered by a specification which will insure a good detail.

Section 38 specifies concrete sufficient in quantity to take the uplift, but does not provide any factor of safety. It is good practice to provide at least $1\frac{1}{2}$ or 2 times the computed uplift in the weight of the concrete. Furthermore, the specification should include a provision that the arrangement of the anchorage in the concrete shall be such as to develop the full weight without depending on the tenacity of the concrete to hold the mass together; otherwise, this provision is apt to be overlooked, thus resulting in bad practice.

Sections 40 and 41 specify that the quality of materials and workmanship shall be according to certain specifications referred to by name. It would add little to the bulk of these specifications and much to their completeness if the specifications for quality of materials and workmanship were written out in full.

Section 42 specifies a shop coat of approved paint. It may be hopeless to try to get the Engineering Profession to agree on an approved paint, but probably red lead would more nearly satisfy the ideas of most members than any other one kind.

The specification has covered only the work of the designer and manufacturer of tanks, but, inasmuch as most contracts for tanks and stand-pipes, especially for municipalities, include their erection, it would seem desirable to give specifications for erection, testing, and field painting.

It is to be regretted that the author did not see fit to give some text with the specifications.

Mr. Hopkins. CHARLES C. HOPKINS, M. AM. SOC. C. E. (by letter).—The author expresses the wish that the general specifications, as submitted in his paper or as finally revised, be adopted by the Engineering Profession. It appears to the writer that, in their present form, the specifications are not drawn as carefully as they should be; that some portions might be omitted, others added, or added to, and other advantageous changes made.

Although the author evidently intends that there shall be a distinction between a stand-pipe and a tank, he has used the word, "tank," in places where either one is or should be meant, and, in other places, where only an elevated tank can be intended.

It is inferred that by "tower" is meant the framework supporting an elevated tank, that a "tank" may be thus elevated or may stand with its bottom at or near the surface of the ground, and that a "stand-pipe" is simply a tank without a supporting tower, but having a height considerably greater than its diameter.

As the author uses the word "tank" at times in a general sense, including stand-pipe, it leaves considerable uncertainty in other places, for example, in Section 31. If it is assumed that stand-pipes are to be roofed, issue might be taken with the author that they are not generally roofed in the colder climates unless enclosed in a building or "tower," because the floating of the ice which forms around the inside would probably lift, and thus ruin, the roof.

The writer suggests that the weight of water should not be assumed to be 63 lb. per cu. ft., when 62.5 lb. is much more nearly correct and is a more convenient number to use; or, what would be better still, that Section 3 be stricken out entirely as being unnecessary.

Section 12 appears to be drawn rather carelessly, in several respects. Why refer to the tanks as "cylindrical"? Does not this section refer to stand-pipes also? What is meant by the plates being of different diameters? Possibly the intention is that the courses forming the sides shall lap over each other inside and outside alternately. What is meant by the expression, "No foreign material shall be allowed when caulking"? In specifying that in oil-tank work "both the inside and outside of the tanks shall be beveled for caulking," the author probably means that the inside and outside edges of the plates shall be beveled for caulking; if so, the wording of the section should be changed.

Although the lapping of the side plates alternately inside and outside is the usual construction, what material objection is there to making each horizonal course (especially in small stand-pipes) slightly conical, so that the top of one course enters the bottom of the one next above it? The writer asks this for information, as he has heard a manufacturer of stand-pipes state that he preferred to build in that

way, believing it would be more satisfactory, as all the inside caulking of the horizontal joints would be over-handed, and would be done more easily and, perhaps, better. Mr. Hopkins.

The author's specifications do not state the manner in which the anchor-bolts are to be fastened to the tank, or the manner in which the bottom of the stand-pipe is to be fastened to the side plates, possibly leaving these points, with others, to be shown on a plan to be submitted, although there is no reference to such a plan in the specifications. As to the connection of the bottom with the side, it is the writer's opinion that for large stand-pipes the use of both inside and outside angles is best, riveting the bottom plates as well as the side plates, to both angles. If either angle is omitted, as it may well be at times, it should be the inner one, because an outside bottom angle gives the stand-pipe a slight additional factor of safety against overturning, and a leak occurring at the angle can be caulked without drawing off the water. Thus far, the writer has always found the outside angle entirely satisfactory.

It is suggested that the specifications should state that all caulking edges shall be planed to a proper bevel, and that all caulking shall be done with a round-nosed tool.

The specifications for the manhole, roof, trap-door, and other details are rather meager, and might perhaps be left out altogether or only made the basis of plans to be submitted by the contractor and to be approved afterward by the engineer. The latter method is not usually as satisfactory as to submit definite plans and specifications on which all contractors may bid.

The meaning of Section 35 is not clear to the writer. Certainly several different meanings could be ascribed to it. If it is assumed that the engineer for the "owner" is designing the foundations on which the stand-pipe is to rest, then Section 38 might well be omitted; but if the contractor for the stand-pipe is to build the foundations also, then a complete specification for concrete should be added to Section 38. Unless the contractor for the stand-pipe, tank, or tower, is to build the foundation, Section 11 and Table 2 might as well be omitted, especially the first half of Table 2, because the engineer in charge must satisfy himself as to the safe loads, and for these no general specifications, such as those proposed by the author, should govern.

In reference to painting, the writer believes that such inaccessible parts as "laps in contact" should be either painted or oiled before leaving the shop. Specifications prepared by him and his associates have usually provided that, before leaving the shop, all steel shall be thoroughly cleaned of rust and scale, and be thoroughly coated with boiled linseed oil; that inaccessible surfaces shall be painted before erection; that, after the stand-pipe has been tested and found to be tight, it shall be painted inside and outside with the paint (or varnish)

Mr. Hopkins. specified; and that no painting shall be done in wet or freezing weather.

Section 16 states that "plates more than $\frac{5}{8}$ in. thick shall be sub-punched and reamed." The writer believes that all punching of plates should be done from the surface which is to be in contact, and that in plates as thick as $\frac{3}{4}$ in., or thereabouts, the rivet holes should be drilled.

The Manufacturers' Standard Specifications, as revised on February 6th, 1903, are excellent for workmanship, as far as they go, but for stand-pipe and tank work they are not as complete as they should be. The writer would suggest the following, as some of the requirements in workmanship, which are more or less necessary, and are not covered by the Manufacturers' or the author's specifications:

All plates and angles shall be shaped to the proper curve by cold rolling; heating or hammering for straightening or curving shall not be allowed, and no scarfing or other work shall be done on the steel below a specified temperature. The diameter of the die used in punching rivet holes shall not exceed that of the punch by more than $\frac{1}{16}$ in. All rivet holes in horizontal seams of stand-pipes may be punched. All parts shall be adjusted to a perfect fit and shall be marked before leaving the shop. Eccentricity of rivet holes, if not sufficient to cause rejection, shall be corrected by reaming, and rivets of larger size shall be used in the holes thus reamed. The engineer or inspector shall have the right to require driven rivets to be cut out at random in order to inspect the quality of the workmanship. Rivet caulking shall not be allowed, but leaky rivets shall be cut out and replaced with new ones. The riveting shall not crack the plates or angles. The plates forming the courses shall be as long as practicable.

Inasmuch as the Manufacturers' Standard Specifications for workmanship are short, it might be well to print them entire, or perhaps only the necessary parts, with any others which might be thought advisable, thus having convenient, for the inspector on erection, the complete specifications governing the work under his charge.

The author's specifications omit mention of the inlet (or outlet) and overflow pipes of stand-pipes, and, although they describe a ladder for a tank, they do not mention one for a stand-pipe—quite a necessary adjunct. It is evident that there should not be an inside ladder in an unenclosed stand-pipe where ice is likely to form.

Assuming that general specifications are needed—of which there may be some doubt—it seems to the writer that, to avoid confusion, it might be best to separate the proposed specifications into specifications for steel stand-pipes and specifications for elevated steel tanks, or to place them under separate headings in the same specifications, following some general specifications of such parts as are common to both.

WILLIAM MURRAY BLACK, M. AM. SOC. C. E.*—The speaker does not feel competent to discuss the questions arising in the design of steel tanks, but desires to present to the Society some recent experience in the design and construction of reinforced concrete tanks, which may be of value. Some time ago, there came under his observation a building having a heavy roof of reinforced concrete with a span of about 30 ft., resting on heavy side walls and an interior row of pillars also of reinforced concrete. It was noticed that, in summer, when the side walls were heated by the sun, the pillars within the building hung from the roof, clearing their foundations, and, of course, placing that much additional strain on the roof. Mr. Black.

A little later, in Cuba, a design for a reinforced concrete water tank was presented to the speaker for approval, in which it was proposed to support the tank, at a height of 39 ft., by reinforced concrete columns placed around the circumference of the bottom of the tank and also toward the center. Having in mind the example previously mentioned, he believed that such an arrangement might prove disastrous, and that all the support should be at the circumference. On consideration, a dome-shaped bottom seemed to be the best, and the design was so made. Two tanks were constructed successfully. They have been satisfactory, have been in use for more than 1½ years, and do not leak. The tank first constructed leaked a very little when first filled, at about four places along the lines of successive courses of concrete. The fissures were small, and the water oozed rather than ran out. They were easily closed. The second tank did not leak at all.

The tanks stand side by side. Each structure is composed of a tank 34 ft. in diameter, and 24¾ ft. high, supported on a tower 39 ft. high. The tank is a right cylinder with a circular base. The tower is decagonal in plan, and consists of a heavy ring cap supporting the tank and a gallery, all resting on ten columns, pentagonal in section, at the angles of the decagon, braced and tied by a ring placed above the middle of their height. The cover of the tank is cone-shaped. The wall of the tank is 0.8 ft. thick for the lower 10 ft., and 0.66 ft. thick above that, and is reinforced with steel rods in the usual manner. The bottom of the tank is a dome 30 ft. in diameter, with a rise of 5 ft. It is 1 ft. thick, and is reinforced radially and with horizontal rings. The resultant horizontal thrust is taken up by a heavy reinforcing ring at the circumference. The allowed stress on the steel was 12 000 lb. per sq. in., and the thickness of the concrete was proportioned for a compressive stress of 500 lb. per sq. in.

In preparation for the construction of the tank, a series of experiments had been made by the Director General of Public Works, Mr.

* Colonel, Corps of Engineers, U. S. A.

Mr. Black. D. Lombillo Clark, on the various methods for making concrete watertight. It was found that the use of alum and soap gave the best results, provided the soap had a vegetable base, and the strength of the concrete was not affected injuriously when the proper proportions of alum and soap were placed dry in the cement before mixing the concrete.

As the work was to be done by contract, the specifications were drawn so as to insure the quality of concrete desired. For the foundations and the base of the columns, the concrete was required to be proportioned so that the quantity of cement should fill the voids in the sand used, and the resulting mortar should be 10% greater in quantity than the volume of the voids of the coarse materials. For the remainder of the columns and for the lower part of the tank bottom, the excess of the mortar was to be 20%, and for the wall of the tank, 25 per cent. It proved a simple matter, after the contractor had furnished the sand and broken stone, to give the required proportions by measure. Before mixing, 15 lb. of powdered alum and 6 lb. of castile soap were added to each barrel of cement used for the highest grade of concrete.

Mr. Porter. J. Madison Porter, Assoc. M. Am. Soc. C. E.—The speaker's practice, based on experience derived from the design and construction of some three hundred stand-pipes in various parts of the United States, differs somewhat from that of the author.

The weight of water is taken almost everywhere at 62.5 lb. per cu. ft., instead of 63 lb.

A live load should be specified for ladders and spiral stairways.

The total wind pressure on single curved surfaces is taken generally at one-half the intensity of the pressure multiplied by the product of the height and the diameter, although the factor $\frac{2}{3}$ is probably preferable to $\frac{1}{2}$. Knowledge in regard to the total wind pressure on large surfaces is certainly lacking, especially when such surfaces are curved.

The working stresses advocated by the author are low, for the material specified, and, with proper workmanship, should give satisfactory results. The speaker has used working stresses of 12 000 lb., on iron plates having an ultimate strength of 48 000 lb., with very good results. This gives a factor of 4, based on the ultimate strength. There are a number of stand-pipes, built more than twenty years ago, some of which have a factor of 3, and some as low as $2\frac{1}{4}$. These stand-pipes are still in use, and, as far as known, have given no trouble; in general, however, such low factors are not advisable.

From Section 12 it would seem that the author advocates cylindrical rings of different diameters, that is, outside and inside rings. This is contrary to the speaker's experience and practice. Inside caulking, on stand-pipes having large and small rings, requires every other

horizontal joint to be caulked upward. This method is unsatisfactory owing to the inconvenient position of the caulker, and generally results in poor work. By using tapered rings, with the smaller diameter on top, this will allow inside and, at the same time, downward caulking. It is well to add that all riveted joints should be caulked from the side from which the rivet is driven. The tail of a driven rivet generally shows small cracks which may cause a leak under pressure, and caulking the joint on the pressure side would not prevent it. In using tapered rings, the rivets are driven from the inside, and the seams are caulked from the inside. Mr. Porter.

The speaker has never found it satisfactory to caulk both the inside and outside of a joint, as one operation is likely to undo all the good of the other. At best, caulking a joint is evidence of imperfection in workmanship, and therefore it should be used only to correct this defect. It does not increase the strength of the joint; and excessive, improper, or defective caulking may become a serious factor in the safety of a stand-pipe.

As outlined in the specifications, the requirements relative to riveted joints, size of rivets, etc., agree approximately with the speaker's practice, and also the specifications regarding sub-punching and reaming all plates having a thickness of more than $\frac{5}{8}$ in. It would be well, however, to state the amount of reaming required.

Section 19 requires all plates to be punched before being bevel-sheared. Most manufacturers to-day do this work on planers, which method is certainly preferable, as shearing is rather a rough treatment for steel, especially for thick plates. The manufacturer would necessarily punch before bevel-planing in order to use the holes for holding-down purposes.

In the speaker's practice, in making beds for flat bottoms, a thickness of about 2 in. of dry mortar, composed of two or three parts of sand to one of Portland cement, is spread on top of the foundation and carefully leveled; then the bottom, previously riveted up, is lowered on this cushion. When the stand-pipe is nearly completed, a depth of about 6 or 8 in. of this dry mortar is removed from around the outside and a 2:1 mortar is used for pointing. This practice has given very good results.

Manholes should be provided with a reinforcing ring, plate, yoke, and holding bolt.

The speaker places an angle (the size depending on the diameter of the stand-pipe) around the outside of the top of the stand-pipe, although a Z-bar is probably preferable.

Stiffening angles around the outside of a stand-pipe at various intervals are extremely unsightly, although, at best, a metallic stand-pipe cannot be classed as an æsthetic structure. Such angles are likely to produce initial stresses in the shell. No stand-pipe having a

Mr. Porter. truly cylindrical shell has yet been constructed. Although the segments forming the shell may have been correctly rolled to templet, the riveting of these plates necessarily bring the section out of round, owing to the rivets receiving harder driving at one section than at another, and this is true, whether rivets are driven by hand or by power. The introduction of the stiffening ring will have a tendency to distort this original section of the stand-pipe, and consequently, to introduce initial stresses. However carefully the work may be done, the shell of every stand-pipe is subjected to considerable initial stresses, owing to the nature of the work and the method necessarily used in erection. The speaker, therefore, does not use stiffening angles, but increases the thickness of the shell if there is any danger that it will collapse under wind pressure.

Outside ladders are desirable, but the speaker would not advocate placing an obstruction, such as a ladder or intake pipe, inside a stand-pipe, in latitudes where ice is likely to form. He knows of a number of stand-pipes originally containing inside ladders, in which such ladders remained less than a year; at the end of the first winter most of them were found at the bottom of the stand-pipe.

The necessity for anchorage can be determined readily from the following equations:

$$W \gtreqless p\ k\ H^2,$$

in which W = the total weight of metal in the stand-pipe, in pounds; p = the intensity of wind pressure on a normal surface; k is a reduction factor, to be used on account of the curvature of the surface; and H = the total height of the stand-pipe, in feet. This formula can be readily derived, on the assumption that anchorage is needed when the tension on the windward side, due to the overturning effect of the wind, is equal to the compression due to the weight of the pipe. When anchor-bolts are required, the speaker spaces them equally around the circumference. The stress in an anchor-bolt may readily be determined from the equation:

$$S = \left(\frac{W - p\ k\ H^2}{D}\right)\frac{1}{n},$$

in which W = the total weight of metal in the stand-pipe, in pounds; d = the diameter; H = the total height, in feet; p = the intensity of pressure; k is a reduction factor, D = the diameter of the anchor-bolt circle, in feet; n = the number of equally-spaced anchor-bolts; and S = the maximum tension on one bolt. This equation is readily obtained by considering the stand-pipe as a cantilever supported by the anchor-bolts.

The author does not mention the connection of the shell with flat bottoms. The speaker uses angle irons having a thickness equal, at least, to that of the bottom ring of the shell. In all cases where triple riveting is necessary for the lower horizontal joints, two bottom

angles are used, in which case the thickness of each angle is not less than two-thirds of the thickness of the bottom ring. Mr. Porter.

E. G. Walker, Jun. Am. Soc. C. E. (by letter).—The writer is in sympathy with Mr. Birch-Nord's efforts to bring about a standardization in the design of elevated tanks of the description treated in his paper, as these structures form a class very suitable for this purpose. The specification appears to cover most of the best points in present-day practice, and the unit stresses proposed are not excessive. It would be of interest, however, to know the reason for the adoption of the factor, $\frac{3}{5}$, in calculating the wind pressure on cylindrical surfaces, referred to in Section 5, in place of $\frac{1}{2}$, as given by Rankine and others, and as generally used for cylindrical chimneys and other structures. Mr. Walker.

Another point is that, although in Section 11 a unit bearing pressure on concrete foundations is given, and concrete is again referred to in Section 38, no specification, either of the materials used or of the proportioning of the mixture, is given. For the sake of completeness, it seems desirable to add this information.

A. W. Carpenter, M. Am. Soc. C. E. (by letter).—The increasing cost of timber and the deterioration in the quality of timber commercially available for tanks are increasing the first cost and decreasing the life of such tanks, so that steel is beginning to appear as a substitute for wood, for railroad locomotive water supply. For capacities in excess of 100 000 gal., an assumed life of 30 years or more for a steel tank, as against a life of 15 years for a wooden tank, and with ordinary construction in each case, steel will now compare favorably in cost or be cheaper than wood. The importance of a proper specification for design and construction, therefore, is apparent. Mr. Carpenter.

The specifications proposed appear to cover most of the ground satisfactorily. The writer would criticise them as being too brief and general, in some particulars, and there are some points to which he would take exception.

The specification for wind pressure on cylindrical tanks does not accord with the usual theory that the pressure on a cylinder is one-half that on a flat surface.

Why is the tension on the net area of tank plates specified as only 12 000 lb. per sq. in.? With the quality of material specified, and proper workmanship, there seems to be no need for such a low tensile unit stress. The writer has used the value, 15 000 lb., recommended by the late J. B. Johnson, M. Am. Soc. C. E., in his work on "Modern Framed Structures," and sees no reason to doubt that this will provide ample strength with an allowance for loss of from 10% to 20% in section, which should never occur with careful maintenance. The writer would like the author to state his full argument for the unit stress given.

The value allowed for $\frac{l}{r} = 180$ for struts seems to be a little high;

Mr. Carpenter. 150 would seem to be more reasonable. Does the writer understand correctly that it is not intended to specify beveling of edges for caulking water tanks? Clause 12 does not seem to be clear on this. The proper angle for bevels should be specified.

The specification permitting small rivets in roof plates to be driven cold without button sets, seems to be unwarranted, as tending toward careless and inferior workmanship.

The writer would inquire, regarding the specification that the workmanship shall be in accordance with the "Manufacturers' Standard Specifications," as to what "Manufacturers" are referred to; he assumes that these are the specifications given in the so-called "Pocket Companion" published by the Carnegie Steel Company. If these specifications had origin other than in the mind of the compiler of this handbook, the writer would be glad to be informed. As applicable to the class of work in question, it would seem that they fail regarding rivet-spacing in tank plates, which should be made, generally, the minimum consistent with preservation of section, in order that tight joints may result. A full specification for rivet-spacing seems to be desirable.

The specification for filling under the bottoms of stand-pipes would be given more value by specifying the proportions of cement and sand to be used, the consistency of the resulting grout, and the method of filling. The writer suggests 1 part of cement to $1\frac{1}{2}$ parts of sand, with water added to make a thin grout, and pouring through pipes 4 ft. long, to be screwed into the tapped holes, so as to give a head to the liquid; also holes for pipes $1\frac{1}{2}$ or 2 in. in diameter, instead of the $1\frac{1}{4}$-in. holes specified.

The paint specification is unsatisfactory in that it does not state the kind of paint which may be expected to give efficient protection. The writer has carried out some experiments to determine the resistance of paint coating, on the interior surfaces of steel pans, to the action of rain-water with which the pans were filled. All the linseed oil and asphalt paints were destroyed in a few months. Two coats of a paint made of coal-tar, Portland cement, and kerosene oil, over a coat of red lead and linseed oil paint, proved the most durable, and is still in good condition after exposure to the water in the pan for more than 400 days. A manufactured paint, with cement, pigment, and oil vehicle, which was used as a priming coat, gave promise of good results if covered with additional coats of the same or of more resistant material than happened to be applied over it in the case of these tests.

It is the writer's opinion that heavy paints with a coal-tar base should be specified for the interior of water-tanks. He believes that it is necessary to apply two field coats of paint over the shop coat, in order to get good results on the inside of water-tanks. The specification should state that the heads of field-driven rivets shall be painted as soon as the rivets are accepted by the inspector, and the shop coat

shall be restored and made complete at all points where injured or omitted, before the field coats are applied. Mr. Carpenter.

The writer has been informed that the interiors of tanks which hold alkaline water will not rust. Information on the preservation of the metal in the interiors of tanks should be presented.

The writer suggests that the erector of the tank be required to guarantee its tightness against leakage, when filled with the liquid which it is designed to hold.

C. W. Birch-Nord, Assoc. M. Am. Soc. C. E. (by letter).—Several of the discussors criticise the concise and concentrated form of the specifications, especially in the way they refer to other standard specifications for manufacture, quality of steel, etc. It was the writer's intention that these specifications should be used only by technical men, familiar with steel structures in general, and he did not think it necessary to include anything not especially required for elevated steel tanks and stand-pipes, as such specifications should only be used as a guide in conjunction with common practice. Mr. Birch-Nord.

The shortcomings of the original specifications have been disclosed by the discussion, and therefore the Revised Specifications appended to this discussion cover material, workmanship, foundations, etc. The specifications for material and foundations are largely copied from those of the American Railway Engineering and Maintenance of Way Association, and from those of C. C. Schneider, Past-President, Am. Soc. C. E.* Two plans, Figs. 3 and 4, showing the general details of an elevated steel tank on a tower, and of a stand-pipe, have been added, and will probably assist in interpreting the specifications. There is also added a table of properties of joints, and a table giving shearing and bearing values for rivets at 9 000 and 18 000 lb. per sq. in., respectively.

Mr. Burdick refers to the use of different unit strains for various climates, but the writer does not think that this will be necessary, as he has designed tanks, using 12 000 lb. per sq. in., very successfully, and for such different places as Texas, Illinois, Minnesota, and California. As ice will only form near the top of a tank, and as the minimum metal has been specified at $\frac{1}{4}$ in., the writer feels assured that this should not cause any alarm. Mr. Burdick's suggestion as to separating tanks from stand-pipes has been adopted in the Revised Specifications.

Mr. Selby calls attention to the fact that tanks with semi-elliptical bottoms have not been mentioned. Such tanks are omitted because they are patented, and this is a general specification.

The weight of water has been assumed at 63 lb. per cu. ft., because water often contains more or less mineral matter.

The unit strain of 12 000 lb. per sq. in. in tank plates is established

* *Transactions*, Am. Soc. C. E., Vol. LIV, p. 371.

Mr. Birch-Nord. because of the bending, excessive punching, scarfing, and other handling to which the plates are subjected.

Tanks and stand-pipes are never truly cylindrical, and therefore there are considerable initial stresses in their materials which cannot be determined; and, as the failure of one of these structures might cause great damage, they should always be designed with unit stresses which are not too high. A structure of this kind can be compared with a dam, for, when it fails, it carries everything before it. This is a good reason for using an ample factor of safety. There are several engineers who do not use higher stresses than 10 000 lb. per sq. in. in tank plates; others go as high as 13 500 lb. per sq. in.; but the writer knows of no one who has advocated stresses as high as 15 000 lb. per sq. in., except the late J. B. Johnson, M. Am. Soc. C. E.

Mr. Selby's interpretation of the allowable shear on rivets is no doubt a mistake. All rivets in tank plates are specified at a shear of 9 000 lb. per sq. in.

The idea as to a "manual of design" and to give minor information relative to the calculation of hydrostatic pressures, etc., will be found unnecessary for the aid of any technical engineer.

The writer does not quite see why short columns should be calculated at 15 000 lb. per sq. in. as a maximum, and feels assured that any of the standard adopted column formulas will give satisfactory results.

Mr. Hopkins calls attention to possible misunderstandings as to the classification of the specifications, etc. This has been remedied, and some of his ideas as to workmanship have been incorporated in the Revised Specifications.

Mr. Walker and Mr. Carpenter ask why the factor, $\frac{2}{3}$, is used in calculating the wind pressure on cylindrical surfaces. This has been recommended by the "Verein Deutscher Ingenieure" and adopted by the German Government, after careful investigation of wind pressures on cylindrical surfaces.

Requirements as to concrete for foundations will be found in the Revised Specifications.

Mr. Black's experience regarding reinforced concrete tanks is very interesting, but can hardly be applied to these specifications.

Mr. Porter refers to the construction and manufacture of the sectional rings for cylindrical tanks, and recommends that these should be slightly conical. The writer, however, finds from observation that practically all manufacturers favor rings of different diameters, placed alternately outside and inside. Mr. Porter's ideas as to caulking agree with the writer's. Rivets are driven from the outside in all cases, as this simplifies the erector's rigging. As to the effect of initial stresses caused by reinforcement rings, Mr. Porter is quite correct, but, in

general, stiffening angles will increase the stiffness of stand-pipes and do more good than possible harm. Mr. Birch-Nord.

The method of connecting the bottom plates with the sides is described in Section 20, Part II, of the Revised Specifications.

The maximum ratio, $\frac{l}{r}$, for main members is specified at 120, and only minor members, such as struts for wind bracing, are specified at 180, which the writer has found to be ample.

Mr. Carpenter will probably find that the Revised Specifications cover quite completely such points as caulking, workmanship, and rivet spacing.

The writer has found it entirely satisfactory to omit the use of button sets for rivets as small as $\frac{1}{4}$ or $\frac{5}{16}$ in. in roof plates; the Revised Specifications, however, state that such rivets "need not be headed with a button set."

In reference to grouting under the bottom plates of stand-pipes, it should hardly be necessary to specify that only cement and sand should be used, as it is not likely that anyone would attempt to use gravel or crushed stone for grouting to be poured through $1\frac{1}{4}$-in. holes. The writer has found it unnecessary to use pipes for grouting, as the holes are only 4 ft. apart.

It would be difficult to select a paint which would satisfy all engineers; therefore the writer has simply specified that "an approved paint" shall be used.

In conclusion, the writer wishes to express his appreciation to those who have contributed to the discussion, and for valuable suggestions which have assisted him in revising these specifications.

REVISED GENERAL SPECIFICATIONS FOR ELEVATED STEEL TANKS ON TOWERS, AND FOR STAND-PIPES.

General Information.

The following points are to be specified by the owner when soliciting proposals for elevated steel tanks on towers, or for stand-pipes:

I.—Elevated Steel Tanks on Towers.

a—Capacity of tank, in gallons or barrels.

b—Height of tower, from top of foundation to bottom of tank with flat bottom, or to point where spherical or conical bottom is connected to cylindrical part of tank.

c—Maximum pressure head required.

d—Character of contents: water, oil, or other fluid.

e—Diameter of riser or inlet pipe, and of outlet pipe.

f—Peculiar features as to location, design, or other information fixing the general dimensions of the tank and tower. It will be preferable for the owner to furnish a sketch showing the general outline of the tank and tower.

g—Tank and tower complete, with indicator, pressure gauges, riser or inlet pipe, overflow pipe, expansion joints for pipes, frost-proof casing, etc., to be furnished by manufacturer, or not.

h—Foundations for tower and riser pipe, etc., to be furnished by manufacturer, or not.

i—Character of bid: lump-sum, pound-price, or material f. o. b. cars or erected; and, also, transportation facilities available.

II.—Stand-Pipes.

a—Capacity of stand-pipe, in gallons or barrels.

b—Height of stand-pipe from top of foundation to extreme top of steel; or specify diameter.

c—Character of contents: water, oil, or other fluid.

d—Peculiar features as to location, design, or other information fixing the general dimensions of the stand-pipe. It will be preferable for the owner to furnish a sketch showing the general outline of the stand-pipe.

e—Foundations for stand-pipe to be furnished by manufacturer, or not.

f—Character of bid; lump-sum, pound-price, or material f. o. b. cars or erected; and, also, transportation facilities available.

Part I.—Design of Elevated Steel Tanks on Towers.

Definition.

1.—An elevated tank is a vessel placed on a tower in order to furnish a certain required pressure head. The tank is filled through a riser or inlet pipe.

2.—Elevated tanks are mostly used in connection with pumping stations, or are connected directly to Artesian wells, in order to store water under pressure.

3.—As practically all tanks are cylindrical, this specification will only have reference to those of that shape.

Loads.

4.—The dead load shall consist of the weight of the structural and ornamental steelwork, platforms, roof construction, piping, etc.

5.—The live load shall be the contents of the tank, the movable load on the platforms and roof, and the wind pressure.

6.—The live load on the platforms and roof shall be assumed at 30 lb. per sq. ft., or a 200-lb. concentrated load applied at any point.

7.—The wind pressure shall be assumed at 30 lb. per sq. ft., acting in any direction. The surfaces of cylindrical tanks exposed to the wind shall be calculated at two-thirds of the diameter multiplied by the height. Similar assumptions may also be made for spherical and conical surfaces by using the correct heights.

8.—The live load on platforms and roof shall not be considered as acting together with the wind pressure.

Unit Strains.

9.—All parts of the structure shall be proportioned so that the sum of the dead and live loads shall not cause the strains to exceed those given in Table 1.

TABLE 1.

Tension in tank plates	12 000 lb. per sq. in.	of net area.
Tension in other part of structure	16 000 " " " " " " "	
Compression	16 000 " " " "	reduced.
Shear on shop rivets and pins	12 000 " " " "	
Shear on field rivets (tank rivets) and bolts	9 000 " " " "	
Shear in plates	10 000 " " " "	of gross area.
Bearing pressure on shop rivets and pins	24 000 " " " "	
Bearing pressure on field rivets (tank rivets)	18 000 " " " "	
Fiber strain in pins	24 000 " " " "	

10.—For compression members, the permissible unit strain of 16 000 lb. shall be reduced by the formula:

$$p = 16\,000 - 70\,\frac{l}{r},$$

where p = permissible working strain in compression, in pounds per square inch;

l = length of member, from center to center of connections, in inches;

r = least radius of gyration of section, in inches.

The ratio, $\frac{l}{r}$, shall never exceed 120 for main members and 180 for struts and roof construction members.

11.—Stresses due to wind may be neglected if they are less than 25% of the combined dead and live loads.

12.—Unit strains in bracing and other members taking wind stresses may be increased to 20 000 lb. per sq. in., except as shown in Section 11.

13.—The pressures given in Table 2 will be permissible on bearing plates.

TABLE 2.

Brickwork with cement mortar	200 lb. per sq. in.
Portland cement concrete	350 " " " "
First-class sandstone	400 " " " "
First-class limestone	500 " " " "
First-class granite	600 " " " "

Details of Construction.

14.—The plates forming the sides of cylindrical tanks shall be of different diameters, so that the courses shall lap over each other, inside and outside, alternately.

15.—The joints for the horizontal seams, and for the radial seams in spherical bottoms, shall preferably be lap joints.

16.—For vertical seams double-riveted lap joints shall be used for $\frac{1}{4}$, $\frac{5}{16}$, and $\frac{3}{8}$-in. plates. Triple lap joints shall be used for $\frac{7}{16}$ and $\frac{1}{2}$-in. plates; double-riveted butt joints shall be used for $\frac{9}{16}$, $\frac{5}{8}$, $\frac{11}{16}$ and $\frac{3}{4}$-in. plates, and triple-riveted butt joints for $\frac{13}{16}$, $\frac{7}{8}$, $\frac{15}{16}$ and 1-in. plates.

17.—Rivets $\frac{5}{8}$ in. in diameter shall be used for $\frac{1}{4}$-in. plates.

" $\frac{3}{4}$ " " " " " " " " $\frac{5}{16}$ " "

" $\frac{7}{8}$ " " " " " " " " $\frac{3}{8}$ to $\frac{7}{8}$-in. plates, inclusive.

Rivets 1 in. in diameter shall be used for $1\frac{5}{16}$-in. and 1-in. plates.

Rivets shall be spaced so as to make the most economical seams (70 to 75% efficiency). A table of riveted joints is given at the end of these specifications.

18.—In no case shall the spacing between rivets along the caulked edges of plates be more than ten times the thickness of the plates. All rivets shall be entered from the inside of the tank, and shall be driven from the outside, that is, new heads on rivets shall always be formed from the opposite side of the plate on which the caulking is done.

19.—Plates $\frac{5}{8}$ in. thick, and not more than $\frac{7}{8}$ in. thick, shall be sub-punched with a punch $\frac{3}{16}$ in. smaller in diameter than the nominal size of the rivets, and shall be reamed to a finished diameter not more than $\frac{1}{16}$ in. larger than the rivet. Plates thicker than $\frac{7}{8}$ in. shall be drilled.

20.—The minimum thickness of the plates for the cylindrical part shall be $\frac{1}{4}$ in. The thickness of the plates in spherical bottoms shall never be less than that of the lower course in the cylindrical part of the tank.

21.—The facilities at the plant where the material is to be fabricated will be investigated before the material is ordered.

22.—All plates shall be sheared or planed to a proper bevel along the edges for caulking.

23.—All plates shall be caulked along the beveled edges from the inside of the tank, and with a round-nosed tool. The use of foreign material for caulking, such as lead, copper, filings, cement, etc., will not be permitted.

24.—The plates in tanks for the storage of oil shall be beveled on both sides for outside and inside caulking.

25.—The radial sections of spherical bottoms shall be made in multiples of the number of columns supporting the tank, and shall be reinforced at the lower parts, where holes are made for piping.

26.—When the center of the spherical bottom is above the point of connection with the cylindrical part of the tank, there shall be provided a girder at said point of connection to take the horizontal thrust. The horizontal girder may be made in connection with a balcony. This also applies where the tank is supported by inclined columns.

27.—The balcony around the tank shall be 3 ft. wide, and shall have a floor-plate $\frac{1}{4}$ in. thick, which shall be punched for drainage. The balcony shall be provided with a suitable railing, 3 ft. 6 in. high.

28.—The upper parts of spherical bottom plates shall always be connected on the inside of the cylindrical section of the tank.

29.—In order to avoid eccentric loading on the tower columns, and local stresses in spherical bottoms, the connections between the columns and the sides of the tank shall be made in such a manner that the center of gravity of the column section intersects the center of connection between the spherical bottom and the sides of the tank. Enough rivets shall be provided above this intersection to transmit the total column load.

30.—If the tank is supported on columns riveted directly to the sides, additional material shall be provided in the tank plates riveted directly to the columns to take the shear. The shear may be taken by providing thicker tank plates, or by reinforcement plates at the column connections, while bending moments shall be taken by upper and lower flange angles. Connections to columns shall be made in such a manner that the efficiency of the tank plates shall not be less than that of the vertical seams.

31.—For high towers, the columns shall have a batter of 1 to 12. The height of the tower shall be the distance from the top of the masonry to the connection of the spherical bottom, or the flat bottom, with the cylindrical part of the tank.

32.—Near the top of the tank there shall be provided one Z-bar to act as a support for the painter's trolley, and for stiffening the tank.

Its section modulus shall be not less than $\frac{D^2}{250}$, where D is the diameter of the tank, in feet. If the upper part of the tank is thoroughly held by the roof construction, this may be reduced.

33.—On large tanks, circular stiffening angles shall be provided in order to prevent the plates from buckling during wind storms. The distance between the angles shall be determined by the formula:

$$d = \sqrt{t}\,\frac{900}{D},$$

where d = approximate distance between angles, in feet;
t = thickness of tank plates, in inches;
D = diameter of tank, in feet.

34.—The top of the tank will generally be covered with a conical roof of thin plates; and the pitch shall be 1 to 6. For tanks up to 22 ft. in diameter, the roof plates will be assumed to be self-supporting. If the diameter of the tank exceeds 22 ft., angle rafters shall be used to support the roof plates, which are generally $\frac{1}{8}$ in. thick.

Plates of the following thicknesses will be assumed to be self-supporting for various diameters:

$\frac{3}{32}$-in. plate, up to a diameter of 18 ft.
$\frac{1}{8}$-in. plate, up to a diameter of 20 ft.
$\frac{3}{16}$-in. plate, up to a diameter of 22 ft.

Rivets in the roof plates shall be from $\frac{1}{4}$ to $\frac{5}{16}$ in. in diameter, and shall be driven cold. These rivets need not be headed with a button set.

35.—A trap-door, 2 ft. square, shall be provided in the roof plate. Near the top of the higher tanks, there shall be a platform with a railing, for the safety of the men operating the trap-door.

36.—There shall be an ornamental finial at the top of the roof.

37.—There shall be a ladder, 1 ft. 3 in. wide, extending from a point about 8 ft. above the foundation to the top of the tank, and also one on the inside of the tank. Each ladder shall be made of two $2\frac{1}{2}$ by $\frac{3}{8}$-in. bars with $\frac{3}{4}$-in. round rungs 1 ft. apart. On large, high tanks, 30 ft. or more in diameter, a walk shall be provided from the column nearest the ladder to the expansion joint on the riser or inlet pipe.

38.—In designing a tank, a height of 6 in. shall be added to the required height of the tank if an overflow pipe is not specified by the owner.

39.—Each elevated tank shall be furnished with a riser or inlet pipe, the size of which shall be determined by the rate at which the tank must be filled. The size of the riser pipe will be specified by the owner. The outlet pipe, in most cases, is not required, as the riser or inlet pipe will serve the same purpose, but it shall be furnished if demanded by the owner.

40.—All pipes entering the tank shall have cast-iron expansion joints with rubber packing, and facilities for tightening such joints.

The expansion joint, generally, shall be fastened to the bottom of the tank with bolts having lead washers. The tank plates shall be reinforced where the pipes enter the tank.

41.—All pipes entering the tank shall be thoroughly braced laterally with adjustable diagonal bracing at the panel points of the tower.

42.—The diagonal bracing in the tower shall preferably be adjustable, and shall be calculated for an initial stress of 3 000 lb. in addition to wind stresses, etc.

43.—The size and number of the anchor-bolts in the tower shall be determined by the maximum uplift when the tank is empty. The anchor-bolts in the tower, where the maximum uplift is greater than 10 000 lb., shall be fastened directly to the columns with bent plates or similar details. In all other cases it will be sufficient to connect the anchor-bolts directly to the base-plates.

The tension in anchor-bolts shall not exceed 15 000 lb. per sq. in. of net area. The minimum section shall be limited to a diameter of 1¼ in. The details shall be made so that the anchor-bolts will develop their full strength, and, at the lower end, they shall be furnished with an anchor-plate, not less than ½ in. thick, to assure good anchorage to the foundation without depending on the adhesion between the concrete and the steel.

44.—The concrete foundation shall be assumed to have a weight of 140 lb. per cu. ft., and shall be sufficient in quantity to take the uplift, with a factor of safety of 1½.

45.—Three-ply frost-proof casing shall be provided, if necessary, around the pipes leading to and from the tank. This casing shall be composed of two layers of ⅞ by 2½-in. dressed lumber, and each layer shall be covered with tar paper or tarred felt, and one outside layer of ⅞ by 2½-in. dressed and matched flooring. The lumber shall be in lengths of about 12 ft. There shall be a 1-in. air space between the layers of lumber, and wooden rings or separators shall be nailed to them every 3 ft. (In very cold climates it is good practice to fill the space between the pipes and the first layer of lumber with hay or similar material.) The frost casing may be square or cylindrical; it shall be braced to the tower with adjustable diagonal bracing, as described for pipes in Section 41.

46.—All detailed drawings shall be subject to the owner's approval before work is commenced.

47.—For materials, workmanship, inspection, painting, and testing, see Part III; for foundations, see Part IV.

Part II.—Design of Stand-pipes.

Definition.

1.—A stand-pipe is a tank, generally cylindrical, used for the storage of water, oil, etc. Its height, in most cases, is considerably

greater than its diameter; it has a flat bottom, and rests directly on its foundation.

2.—Stand-pipes are economical only in special cases: where their capacity is more important than pressure, or where local conditions are such that an elevated tank is not required.

3.—Stand-pipes for the storage of oil are an exception. These are generally of very large diameter, while the height may not exceed 40 ft.; they are usually referred to as tanks.

4.—Stand-pipes are filled and emptied through pipes connected with their sides or bottom, and are provided with manholes for cleaning purposes.

5.—In cold climates roofs are generally omitted on stand-pipes used for water supply, on account of the formation of ice. In warmer climates there may be roofs in order to prevent the water from becoming a breeding place for mosquitos, flies, etc. Stand-pipes used for the storage of oil or other fluids from which rain-water is to be excluded should always be roofed.

Loads.

6.—The dead load shall consist of the weight of structural and ornamental steel work, and the roof construction, if any.

7.—The live load shall be the contents of the stand-pipe, the movable load on the eventual roof, and the wind pressure.

8.—The eventual live load on the roof shall be assumed at 30 lb. per sq. ft., or a 200-lb. concentrated load applied at any point.

9.—The wind pressure shall be assumed at 30 lb. per sq. ft., acting in any direction. The surfaces of cylindrical stand-pipes exposed to the wind shall be calculated at two-thirds of the diameter multiplied by the height.

10.—The eventual live load on the roof, if the stand-pipe is roofed, shall not be considered as acting together with the wind pressure.

11.—All parts of the structure shall be proportioned so that the sum of the dead and live loads shall not exceed those given in Table 3.

TABLE 3.

Tension in plates forming sides or bottom of stand-pipes	12 000 lb.	per sq. in. of net area.
Tension in roof construction	15 000 "	" " " " " "
Compression in roof construction	16 000 "	" " " " reduced.
Shear on shop rivets in roof, etc	12 000 "	" " " "
Shear on field rivets (in stand-pipe plates) and bolts	9 000 "	" " " "
Shear in plates	10 000 "	" " " "
Bearing pressure on shop rivets	24 000 "	" " " "
Bearing pressure on field rivets (in stand-pipe plates)	18 000 "	" " " "

12.—For compression members in the roof construction, the permissible unit strain of 16 000 lb. shall be reduced by the formula:

$$p = 16\,000 - 70\,\frac{l}{r},$$

where p = permissible working strains in compression, in pounds per square inch;

l = length of member, from center to center of connections, in inches;

r = least radius of gyration of section, in inches.

The ratio, $\frac{l}{r}$, shall never exceed 180.

13.—Stresses due to wind may be neglected if they are less than 25% of the combined dead and live loads.

14.—The average permissible pressures on masonry shall be as given in Table 2, Part I.

Details of Construction.

15.—The plates forming the sides of the stand-pipe shall be of different diameters, so that the courses shall lap over each other, inside and outside, alternately.

16.—The joints for the horizontal seams in the sides, and for the bottom plates, shall preferably be lap joints.

17.—For further information regarding riveted joints, etc., see Part I, Sections 16, 17, 18, and 19.

18.—The minimum thickness of the plates forming the sides shall be $\frac{1}{4}$ in., and $\frac{5}{16}$ in. for the bottom plates, except for oil tanks on a sand foundation. The bottom plates for ordinary stand-pipes shall be provided with tapped holes, $1\frac{1}{4}$ in. in diameter, with screw plugs, spaced at about 4-ft. centers, to permit of filling with cement grout on top of the foundation of the masonry while the bottom part is being erected, in order to secure proper bearing.

19.—Oil tanks of large diameter are generally set directly on a sand foundation, and do not need any holes in the bottom plates for filling beneath with cement grout. In such cases, $\frac{1}{4}$-in. bottom plates will be sufficient.

20.—The bottom plates shall be connected with the sides by an angle iron riveted inside the stand-pipe. This angle iron shall be bevel-sheared for caulking along both legs. For the caulking of plates, see Part I, Sections 22 and 23.

21.—On the side and near the bottom there shall be a 12 by 18-in. manhole of elliptical shape. In the same manner, or on the bottom plates, flanges shall be provided for the connection of inlet and outlet pipes of the sizes specified by the owner. All openings in stand-pipes shall be properly reinforced by forged rings or plates.

22.—For stiffening angles, etc., see Part I, Sections 32 and 33.

23.—In cases where a roof is used see Section 5; Sections 34, 35, and 36 of Part I should also be followed.

24.—There shall be an outside ladder, 1 ft. 3 in. wide, extending from a point about 8 ft. above the foundation to the top of the stand-

pipe. The ladder shall be made of two $2\frac{1}{2}$ by $\frac{3}{8}$-in. bars with $\frac{3}{4}$-in. round rungs 1 ft. apart. An inside ladder will not be required. (In no case should inside ladders be provided on stand-pipes in climates where ice will form. Owners of oil tanks often specify stairways to take the place of ladders.) All ladders shall be able to sustain a concentrated load of at least 800 lb.

25.—Large stand-pipes for oil storage, the heights of which are very small compared with their diameter, will generally be set directly on a sand foundation, and will not need any anchorage whatever, as the overturning moment is very small in comparison with the resisting moment.

26.—Stand-pipes of the ordinary type, for water storage, shall be set on concrete foundations, and shall be anchored thoroughly thereto with anchor-bolts not less than $1\frac{1}{4}$ in. in diameter, set deep enough to take the necessary uplift, and provided with an anchor-plate not less than $\frac{1}{2}$ in. thick in the masonry. All anchor-bolts shall be connected directly to the sides of the stand-pipe with bent plates or similar details. The unit stress in anchor-bolts shall not exceed 15 000 lb. per sq. in. of net area. See Part I, Section 43.

27.—All detailed drawings shall be subject to the owner's approval before work is commenced.

28.—For materials, workmanship, inspection, painting, and testing, see Part III; for foundations, see Part IV.

Part III.—Materials, Workmanship, Inspection, Painting, and Testing.

1.—The steel shall be made by the open-hearth process.

2.—The chemical and physical properties shall conform to the following limits:

Elements considered.	Structural steel.	Rivet steel.
Phosphorus, maximum { Basic	0.04%	0.04%
Phosphorus, maximum { Acid	0.06%	0.04%
Sulphur, maximum	0.05%	0.04%
Ultimate tensile strength, in pounds per square inch	Desired. 60 000	Desired. 50 000
Elongation: minimum percentage in 8 in. Fig. 1	1 500 000	1 500 000
Elongation: minimum percentage in 2 in. Fig. 2	Ultimate tensile strength. 22	Ultimate tensile strength. .....
Character of fracture	Silky.	Silky.
Cold bends without fracture	180° flat.	180° flat.

The yield point, as indicated by the drop of beam, shall be recorded in the test reports.

3.—If the ultimate strength varies more than 4 000 lb. from that

desired, a re-test shall be made on the same gauge, which, to be acceptable, shall be within 5 000 lb. of the desired ultimate.

4.—Chemical determinations of the percentages of carbon, phosphorus, sulphur, and manganese shall be made by the manufacturer from a test ingot taken at the time of the pouring of each melt of steel, and a correct copy of such analysis shall be furnished to the engineer or his inspector. Check analyses shall be made from finished material, if called for by the purchaser, in which case an excess of 25% above the required limits will be allowed.

5.—Specimens for tensile and bending tests, for plates, shapes, and bars, shall be made by cutting coupons from the finished product, which shall have both faces rolled and both edges milled to the form shown by Fig. 1; or with edges parallel; or they may be turned to a diameter of $\frac{3}{4}$ in. for a length of at least 9 in., with enlarged ends.

6.—Rivet rods shall be tested as rolled.

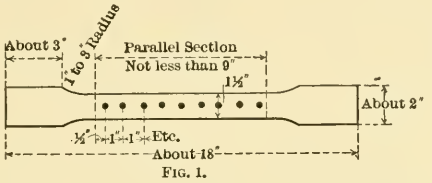


FIG. 1.

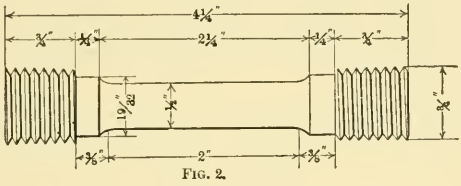


FIG. 2.

7.—Specimens shall be cut from the finished rolled or forged bar, in such manner that the center of the specimen shall be 1 in. from the surface of the bar. The specimen for the tensile test shall be turned to the form shown by Fig. 2. The specimen for the bending test shall be 1 in. by $\frac{1}{2}$ in. in section.

8.—Material which is to be used without annealing or further treatment shall be tested in the condition in which it comes from the rolls. When material is to be annealed, or otherwise treated before use, the specimens for tensile test representing such material shall be cut from properly annealed or similarly treated short lengths of the full section of the bar.

9.—At least one tensile and one bending test shall be made from each melt of steel as rolled. In case steel differing $\frac{3}{8}$ in. and more in thickness is rolled from one melt, a test shall be made from the thickest and thinnest material rolled.

10.—For material less than $\frac{5}{16}$ in. and more than $\frac{3}{4}$ in. in thickness, the following modifications will be allowed in the requirements for elongation:

a—For each $\frac{1}{16}$ in. in thickness below $\frac{5}{16}$ in., a deduction of $2\frac{1}{2}$ from the specified percentage will be allowed.

b—For each $\frac{1}{8}$ in. in thickness above $\frac{3}{4}$ in., a deduction of 1 from the specified percentage will be allowed.

11.—Bending tests may be made by pressure or by blows. Plates, shapes, and bars less than 1 in. thick shall bend as called for in Section 2.

12.—Angles $\frac{3}{4}$ in. and less in thickness shall open flat, and angles $\frac{1}{2}$ in. and less in thickness shall bend shut, cold, under blows of a hammer, without sign of fracture. This test will be made only when required by the inspector.

13.—Rivet steel, when nicked and bent around a bar of the same diameter as the rivet rod, shall give a gradual break and a fine, silky, uniform fracture.

14.—Finished material shall be free from injurious seams, flaws, cracks, defective edges, or other defects, and have a smooth, uniform, workmanlike finish. Plates 36 in. in width and less shall have rolled edges.

15.—Every finished piece of steel shall have the melt number and the name of the manufacturer stamped or rolled upon it. Steel for pins shall be stamped on the end. Rivet and lattice steel and other small parts may be bundled, with the above marks on an attached metal tag.

16.—Material which, subsequent to the foregoing tests at the mills, and its acceptance there, develops weak spots, brittleness, cracks, or other imperfections, or is found to have injurious defects, will be rejected at the shop, and shall be replaced by the manufacturer at his own cost.

17.—A variation in cross-section or weight of each piece of steel of more than $2\frac{1}{2}\%$ from that specified will be sufficient cause for rejection, except in case of sheared plates, which will be covered by the following permissible variations, which are to apply to single plates:

Plates weighing $12\frac{1}{2}$ lb. per sq. ft. or more.

a—Up to 100 in. wide, $2\frac{1}{2}\%$ above or below the prescribed weight;

b—100 in. wide or more, 5% above or below.

Plates weighing less than $12\frac{1}{2}$ lb. per sq. ft.:

a—Up to 75 in. wide, $2\frac{1}{2}\%$ above or below;

b—75 in., and up to 100 in. wide, 5% above or 3% below;

c—100 in. wide or more, 10% above or 3% below.

18.—Plates will be accepted if their thickness is not more than 0.01 in. less than that ordered.

19.—An excess over the nominal weight, corresponding to the dimensions on the order, will be allowed for each plate, if not more than that shown in Table 4, 1 cu. in. of rolled steel being assumed to weigh 0.2833 lb.

TABLE 4.

Thickness, in inches.	Nominal weight, in pounds per square foot.	Width of Plates.		
		Up to 75 in.	75 in. and up to 100 in.	100 in. and up to 115 in.
$\frac{1}{4}$	10.20	10%	14%	18%
$\frac{5}{16}$	12.75	8%	12%	16%
$\frac{3}{8}$	15.3	7%	10%	13%
$\frac{7}{16}$	17.85	6%	8%	10%
$\frac{1}{2}$	20.4	5%	7%	9%
$\frac{9}{16}$	22.95	$4\frac{1}{2}$%	$6\frac{1}{2}$%	$8\frac{1}{2}$%
$\frac{5}{8}$	25.5	4%	6%	8%
More than $\frac{5}{8}$	.....	$3\frac{1}{2}$%	5%	$6\frac{1}{3}$%

Cast Iron.

20.—Except where chilled iron is specified, castings shall be made of tough, gray iron, with not more than 0.10% of sulphur. They shall be true to patterns, out of wind, and free from flaws and excessive shrinkage. If tests are demanded, they shall be made on the "Arbitration Bar" of the American Society for Testing Materials, which is a round bar, $1\frac{1}{4}$ in. in diameter and 15 in. long. The transverse test shall be made on a supported length of 12 in. with the load at the middle. The minimum breaking load thus applied shall be 2 900 lb., with a deflection of at least $\frac{1}{10}$ in. before rupture.

Workmanship, Inspection, and Painting.

21.—All parts forming the structure shall be built in accordance with approved drawings. The workmanship and finish shall be equal to the best in modern shop practice.

22.—All material shall be thoroughly straightened in the shop, by methods which will not injure it, before being laid off or worked in any way.

23.—The shearing shall be done neatly and accurately, and all portions of the work exposed to view shall have a neat and uniform appearance.

24.—The size of each rivet, called for by the plans, shall be understood to mean the actual size of the cold rivet before it is heated.

25.—All plates and shapes shall be shaped to the proper curve by cold rolling; heating or hammering for straightening or curving will not be allowed.

26.—Plates to be scarfed may be heated to a cherry-red color, but not hot enough to ignite a piece of dry wood when applied to it. Most careful attention shall be paid to all scarfing.

27.—All plates or shapes shall be punched before being bevel-sheared or planed for caulking.

28.—All screw threads shall make tight fits in the nuts and turn-buckles, and shall be United States Standard, except for diameters greater than $1\frac{3}{8}$ in., when they shall have six threads per inch. The dimensions of screws of various sizes shall be as follows:

Diameter of screw ends.....	1 in.	$1\frac{1}{8}$ in.	$1\frac{1}{4}$ in.	$1\frac{3}{8}$ and greater.
Number of threads per inch.....	8	7	7	6

The minimum excess at the root of the thread over the body of the bar shall be 15 per cent.

The shape of the thread shall be U. S. Standard.

TABLE 5.—Standard Upsets for Round and Square Bars.

Round Bars.		Square Bars.	
Bar.	Upset.	Bar.	Upset.
Diameter, in inches.	Diameter, in inches.	Side, in inches.	Diameter, in inches.
$\frac{3}{4}$	1	$\frac{3}{4}$	$1\frac{1}{8}$
$\frac{7}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{4}$
1	$1\frac{3}{8}$	1	$1\frac{1}{2}$
$1\frac{1}{8}$	$1\frac{1}{2}$	$1\frac{1}{8}$	$1\frac{5}{8}$
$1\frac{1}{4}$	$1\frac{5}{8}$	$1\frac{1}{4}$	$1\frac{7}{8}$
$1\frac{3}{8}$	$1\frac{3}{4}$	$1\frac{3}{8}$	2
$1\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{1}{2}$	$2\frac{1}{4}$
$1\frac{5}{8}$	2	$1\frac{5}{8}$	$2\frac{3}{8}$
$1\frac{3}{4}$	$2\frac{1}{8}$	$1\frac{3}{4}$	$2\frac{1}{2}$
$1\frac{7}{8}$	$2\frac{1}{4}$	$1\frac{7}{8}$	$2\frac{3}{4}$
2	$2\frac{3}{8}$	2	$2\frac{7}{8}$

29.—The diameter of the die used in punching rivet holes shall not exceed that of the punch by more than $\frac{1}{16}$ in. All rivet holes shall be punched, except as stated in Part I, Section 19.

30.—All punched and reamed holes shall be clean cuts, without torn or ragged edges. The burrs on all reamed holes shall be removed by a tool, countersinking not more than $\frac{1}{16}$ in. Any parts of the structure in which difficulties may arise in field riveting, shall be assembled in the shop and marked properly before shipment.

31.—Rivet holes shall be accurately spaced; eccentrically located rivet holes, if not sufficient to cause rejection, shall be corrected by reaming, and rivets of larger size shall be used in the holes thus reamed.

32.—The use of drift-pins will be allowed only for bringing together several parts forming part of the structure; force will not be allowed to be used in drifting under any circumstances.

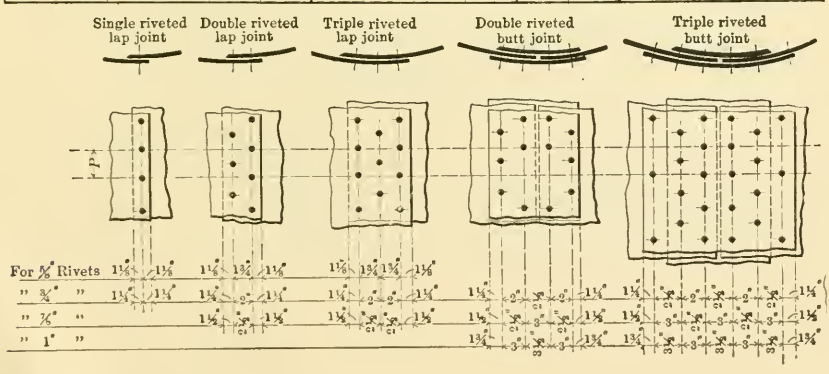
TABLE 6.—Properties for Water-tight Joints.

	Thickness of plate	Number of rows of rivets	⅝″ Rivets: Efficiency of joints in per cent	⅝″ Rivets: Pitch of rivets in inches	⅝″ Rivets: Effective section of plates	¾″ Rivets: Efficiency of joints in per cent	¾″ Rivets: Pitch of rivets in inches	¾″ Rivets: Effective section of plates	⅞″ Rivets: Efficiency of joints in per cent	⅞″ Rivets: Pitch of rivets in inches	⅞″ Rivets: Effective section of plates	1″ Rivets: Efficiency of joints in per cent	1″ Rivets: Pitch of rivets in inches	1″ Rivets: Effective section of plates
Lap Joints	¼″	1	48.7	1⅝	0.121									
		2	**70.7**	2⅛	**0.177**									
	5/16	1	39.5	1⅝	0.124	47.1	2¼	0.147						
		2	65.4	2¼	0.205	**70.5**	3	**0.220**						
	⅜	2	61.3	2	0.230	66.6	2⅛	0.250	**70.7**	3⅛	**0.265**			
		3	70.8	2⅛	0.265	75.6	3⅛	0.284	73.2	3⅛	0.274			
	7/16	2				63.5	2⅜	0.279	66.5	3	0.291			
		3				72.3	3⅛	0.317	**75.2**	4	**0.329**			
	½	2				58.9	2¼	0.295	63.8	2⅜	0.319			
		3				69.4	2⅝	0.347	**72.6**	3¼	**0.363**			
	9/16	2							61.0	2⅝	0.344			
		3							70.5	3⅛	0.397			
Butt Joints	7/16	2				72.0	3⅛	0.315	72.3	3⅜	0.316			
		3				82.2	3⅛	0.359	84.7	3⅛	0.370			
	½	2				72.0	3⅛	0.360	72.3	3⅛	0.362			
		3				80.8	3⅛	0.405	82.8	3⅛	0.415			
	9/16	2				72.0	3⅛	0.405	**72.3**	3⅛	**0.407**			
		3				80.5	3⅛	0.453	82.1	3⅛	0.463			
	⅝	2				70.7	3	0.442	**72.3**	3⅜	**0.452**			
		3				78.4	3	0.490	81.0	3⅜	0.506			
	11/16	2				68.3	2⅞	0.469	**72.3**	3⅛	**0.198**			
		3				75.7	2¾	0.522	80.3	3⅛	0.552			
	¾	2				66.4	2⅞	0.498	**70.2**	3⅛	**0.526**			
		3				73.8	2⅞	0.553	78.0	3⅜	0.585			
	13/16	2							68.3	3¼	0.555			
		3							**75.5**	3¼	**0.611**			
	⅞	2							66.5	3	0.582			
		3							**74.1**	3	**0.647**			
	15/16	2	Note:									70.1	3⅜	0.657
		3	Heavy figures indicate									**76.5**	3⅜	**0.717**
	1″	2	economical riveted joints									67.3	3½	0.673
		3										**74.7**	3½	**0.737**

Note: The distances between rivets at caulked edges shall never exceed 10 times the thickness of plates or straps. The thickness of each strap for butt joints shall never be less than half the thickness of the plates plus 1/16 inch.

SHEARING AND BEARING VALUE OF RIVETS.

Diameter of rivets, in inches	Area in square inches	Single Shear at 9000 lb. per sq. in.	Bearing value for different thicknesses of plates, in inches, at 18000 lb. per sq. in.													
			¼″	5/16″	⅜″	7/16″	½″	9/16″	⅝″	11/16″	¾″	13/16″	⅞″	15/16″	1″
⅝	0.3068	2761	2813	3516	4219	4922	5625	6328	7031						
¾	0.4418	3976	3375	4219	5063	5906	6750	7594	8438	9281	10125				
⅞	0.6013	5412	3938	4922	5906	6891	7875	8859	9844	10828	11813	12797	13781		
1	0.7854	7069	4500	5625	6750	7875	9000	10125	11250	12375	13500	14625	15750	16875	18000



33.—The use of sledges in driving or hammering any part of the structure will not be allowed. Care shall be taken to prevent material from falling, or from being in any way subjected to heavy shocks.

34.—Rivets shall be driven by pressure tools wherever possible. Pneumatic hammers shall be used in preference to hand-driving. All rivet heads shall be concentric with the holes.

35.—All caulking shall be done with a round-nosed tool, and only by experienced and skilled men. Caulking around rivet heads will not be allowed. All leaky rivets shall be cut out and replaced with new ones. All fractured material shall be replaced free of cost to the owner.

36.—If the owner furnishes an inspector, he shall have full access, at all times, to all parts of the shop where material under his inspection is being manufactured.

37.—The inspector shall stamp with a private mark each piece accepted. Any piece not thus marked may be rejected at any time, and at any stage of the work. If the inspector, through oversight or otherwise, has accepted material or work which is defective or contrary to these specifications, this material, no matter in what stage of completion, may be rejected by the owner.

Painting and Testing.

38.—Before leaving the shop, all steelwork excepting the laps in contact on the tank work, shall receive one coat of approved paint or boiled linseed oil. All parts which will be inaccessible after erection shall be well painted, except as stated before.

39.—After the structure is erected and all seams have been caulked, it shall be tested for water-tightness, and leaky places shall be chalked or marked. The water shall then be discharged and the leaky seams shall be caulked. Leaky rivets shall be treated as per Section 35. After the structure has been standing empty for 3 days it shall be re-tested, and then, if all joints are water-tight, it shall be given one coat of approved paint both inside and outside of the tank or stand-pipe. Painting in the open air shall never be done in wet or freezing weather. The owner will select the color of the final coat of paint.

40.—The contractor shall guarantee the tightness of the tank, or stand-pipe, against leakage, when filled with the liquid it is designed to contain.

PART IV.—FOUNDATIONS FOR ELEVATED TANKS ON TOWERS, AND FOR STAND-PIPES.

1.—The average permissible pressure on the soil is as follows:

Soft clay	1 ton	per	square	foot.
Ordinary clay	2 tons	"	"	"
Dry sand and dry clay	3 tons	"	"	"
Hard clay	4 tons	"	"	"
Gravel and coarse sand	6 tons	"	"	"

2.—In all cases a thorough investigation of the ground and the site shall be made before proceeding with the foundations.

3.—All foundations shall be carried below the frost line, and the anchor-bolts shall be placed deep enough to develop their full strength.

4.—In foundations for towers with inclined legs supporting elevated tanks care shall be taken that the piers are constructed in such a manner that the resultant of the vertical and horizontal forces, due to direct loads, passes through the center of gravity of the piers.

5.—Foundations, in general, shall be of concrete composed of 1 part Portland cement, 3 parts sand, and 5 parts crushed stone or gravel. In special cases, where part of the foundation is under water, the concrete shall be a 1:2:4 mixture.

6.—The cement shall be Portland, and shall meet the requirements of the standard specifications adopted by the Special Committee of the American Society of Civil Engineers, on Uniform Tests of Cement.

7.—The sand shall be clean, sharp, coarse, and of grains varying in size. It shall be free from sticks and other foreign matter, except clay or loam, of which it may contain not more than 5 per cent. Crusher dust, screened to reject all particles more than ¼ in. in diameter, may be used instead of sand, provided it meets the owner's approval.

8.—The stone shall be sound, hard, and durable, and shall be crushed to sizes not exceeding 2 in. in any dimension.

9.—The gravel shall be composed of clean pebbles of hard and durable stone, not exceeding 2 in. in diameter, and shall be free from clay and other impurities, except sand. When containing sand in any considerable quantity, the proper proportion shall be maintained in the concrete mixture.

10.—The water shall be clean, reasonably clear, and free from sulphuric acid or strong alkalies.

11.—The mixing will generally be done by hand, in batches not to exceed 1 cu. yd. A machine mixer may be used wherever the volume of work will justify the expense of installing the plant. The requirements for the mixer machine shall be, that the proportions of the materials can be controlled, that the product delivered shall have the required consistency, and that it shall be thoroughly mixed.

12.—The concrete shall be of such consistency that when dumped in place it will not require much tamping. It shall be spaded down and tamped sufficiently to level it off, and so that the water will rise freely to the surface.

13.—The forms shall be well built, substantial, and unyielding, and shall conform to the lines given. The forms for that part of the foundation above the ground shall be of lumber of uniform thickness, dressed on one side and both edges, and shall be free from loose knots.

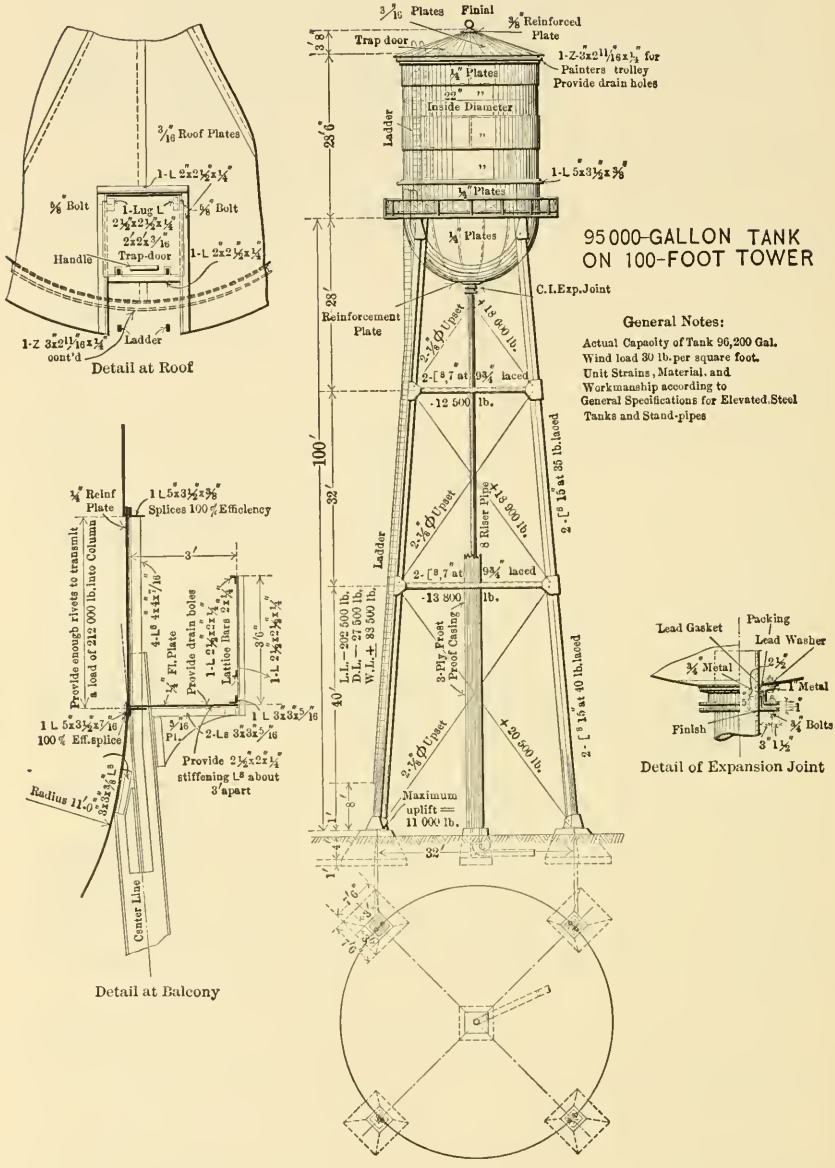

95 000-GALLON TANK
ON 100-FOOT TOWER
General Notes:
Actual Capacity of Tank 96,200 Gal.
Wind load 30 lb. per square foot.
Unit Strains, Material, and
Workmanship according to
General Specifications for Elevated Steel
Tanks and Stand-pipes
Detail at Roof
Detail at Balcony
Detail of Expansion Joint
Finial
Trap door
Inside Diameter
Ladder
Reinforcement Plate
C.I.Exp.Joint
Maximum uplift = 11 000 lb.
Center Line
Radius 11'-0"
Lead Gasket
Packing
Lead Washer
Metal
Finish
Bolts

FIG. 3.

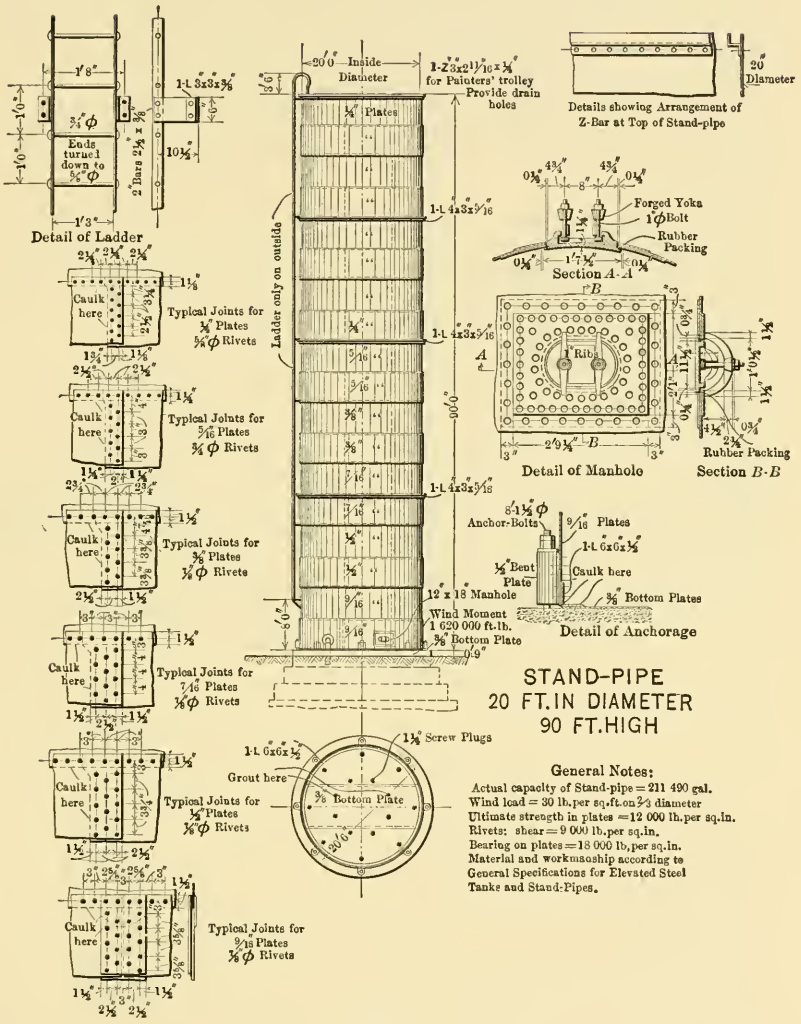

Detail of Ladder
Ends turned down to
Typical Joints for Plates Rivets
Ladder only on outside
Inside Diameter
Plates
Details showing Arrangement of Z-Bar at Top of Stand-pipe
Diameter
Forged Yoke
Bolt
Rubber Packing
Section A-A
Detail of Manhole
Section B-B
Anchor-Bolts
Bent Plate
Caulk here
Bottom Plates
Detail of Anchorage
12 x 18 Manhole
Wind Moment
1 620 000 ft.lb.
Bottom Plate
Screw Plugs
Grout here
STAND-PIPE
20 FT. IN DIAMETER
90 FT. HIGH
General Notes:
Actual capacity of Stand-pipe = 211 490 gal.
Wind load = 30 lb. per sq. ft. on ⅔ diameter
Ultimate strength in plates = 12 000 lb. per sq. in.
Rivets: shear = 9 000 lb. per sq. in.
Bearing on plates = 18 000 lb. per sq. in.
Material and workmanship according to
General Specifications for Elevated Steel
Tanks and Stand-Pipes.

FIG. 4.

For parts of the foundation which are not visible, and for other rough parts, undressed lumber may be used. All lumber shall be clean and free from dry sand or cement before being used.

14.—Where corners or projections in the masonry would be subject to injury, suitable mouldings shall be placed in the angles of the forms to round or bevel them off. Cap stones may be used on the foundations if specified by the owner.

15.—The forms shall not be removed until 36 hours after all the concrete in that section has been placed. In freezing weather they shall remain until the concrete has had a sufficient time to become thoroughly hardened.

16.—In dry, but not freezing weather, the forms shall be drenched with water before the concrete is placed against them.

17.—All concrete shall be deposited in horizontal layers of uniform thickness. All concrete shall be placed immediately after it is mixed, and any having an initial set shall be rejected.

18.—The facing of the foundations shall be made by carefully working the coarse material back from the forms with a shovel, bar, or similar tool, so as to bring an excess of mortar to the face.

19.—Embedding large stones in the interior of the foundations for stand-pipes will be accepted as good practice when it results in a saving. The embedded stones shall be good and sound, shall have rough, sharp corners and edges, and shall never be placed where they will interfere with the anchor-bolts.

20.—The top of the foundation will generally be from 9 to 12 in. above the ground level, unless otherwise specified by the owner.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1117.

ADDRESS AT THE 41ST ANNUAL CONVENTION, BRETTON WOODS, NEW HAMPSHIRE, JULY 6TH, 1909.

By Onward Bates, President, Am. Soc. C. E.

It is the duty of the President of the American Society of Civil Engineers to address its members at each Annual Convention, and in this year of our Lord, 1909, and the fifty-seventh of the Society, I have chosen as my subject, "The Status of the Civil Engineers' Profession in the United States of America."

In determining the status of the profession, it is necessary to consider what it is, what are its objects, what it owes to the community, and what is due to it from the public. To ascertain what it is, requires a knowledge of the qualifications necessary for its practice, and what should be expected of its members in their relations with each other and with their employers.

Since this is an address to the members of the American Society of Civil Engineers, it should set forth the relation of the Society to the profession at large, and the Society's obligation to elevate the profession. I realize that I have undertaken a difficult task, and that all I can hope to accomplish is to interest the members of the Society, and to incite them to personal efforts for the improvement of their chosen profession and its establishment upon a more secure professional basis.

Engineers have long desired a concise and sufficient definition of the profession, and failing to obtain one that is satisfactory, have

usually fallen back on the old one, attributed to Thomas Tredgold, as it is given in the Charter of the Institution of Civil Engineers, dated June 3d, 1828, which is as follows:

"The profession of a Civil Engineer, being the art of directing the Great Sources of Power in Nature for the use and convenience of man, as the means of production and of traffic in states both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation and docks, for internal intercourse and exchange, and in the construction of ports, harbours, moles, breakwaters and light-houses, and in the art of navigation by artificial power for the purposes of commerce, and in the construction and adaptation of machinery, and in the drainage of cities and towns."

In the eighty-one years since the incorporation of the British Institution, no better definition than the one given by Tredgold has been submitted, and perhaps no better definition could have been offered. It was thoroughly comprehensive of the duties of an Engineer in the state of civilization at that period. Since then, in the unparalleled progress of civilization, his duties have been enlarged, diversified, and multiplied, until it seems impossible to state in words what may reasonably be expected of a Civil Engineer at the present time.

Engineers are made, not born. They are pre-eminently "self-made men," the product of their own works, men producing experience and experience making men. With constant achievement in directing the great sources of power in Nature, the Engineer's vision has expanded and his capacity has increased until at the present time he may justly claim the recognition of the world for what the profession has done for the use and convenience of Man along all the lines indicated by Tredgold, and in many others not even dreamed of in that day. The profession is young, just in its infancy, and its scope is so comprehensive, and its growth so rapid that it cannot be defined in a few words.

It is plain that the Engineer of to-day must live up to his privileges, must equal and add to the great achievements of the past, and must continue to progress in the unlimited field of professional work. The Engineer has always been a worker, living for others rather than for himself. His mind has been fixed on professional achievement without regard to personal advancement. He has shown himself to be the greatest source of power in Nature, and his reward has been mainly in the accomplishment of good for his fellow-men.

He is a builder and not a destroyer, adding to the comfort of living for the whole community, and increasing the wealth of the nation. His gain is not based on the loss of others, and the community has not even returned to him the equivalent for what he has given.

Engineers may be justly proud of their calling, and yet it must be recognized that, professionally, they are not well established, either among themselves or in their relations to the public, and that the status of the profession at the present time is not such as they should be satisfied to rest upon.

Any survey of the status of the Civil Engineer is rendered difficult by the diversity of qualifications and requirements. It is frequently stated that the public, which furnishes the means of employment for the Engineer, has little conception of what the work of an Engineer really is, and this is not strange, since Engineers have so much difficulty in defining their calling. This is an age of specialties, and it is a sufficient achievement for an Engineer to become proficient in one line of employment; consequently, an Engineer is engaged to perform any designated work on the basis of his experience and proficiency in executing similar works. As a result, the opinion is formed in the mind of his employer that the field of engineering is restricted to the particular class of work for which he has required an engineer's services. This error is also common in the profession, for the reason that engineers expend their talents in certain lines, and become so engrossed in them that they acquire a limited appreciation of other classes of engineering work.

For the purpose of analyzing the profession and classifying it according to the nature of employment, an analysis has been made from the List of Members of this Society dated February, 1909, showing what each of the 2 380 Members has stated to be his occupation. In selecting this limited number, no reflection is intended on the Associate Members, nor on the qualified engineers of this country who are not connected with the Society. It is considered that the Members furnish a sufficient number of representative engineers for a basis of investigation, and that no better list of experienced Civil Engineers can be obtained, since admission to the grade of Member is a certificate of professional attainments and experience, and it is doubtless, also, a fact that, the majority of the engineers of America who are qualified for the grade of Member, are already enrolled as

such. The distribution of this list of Members with regard to their occupation, as stated by themselves, is as follows:

U. S. Government Service.			
Army Officers	41		
United States Assistant Engineers, etc.	61		
Navy	25		
Reclamation Service	29		
Geological Survey	7		
Coast and Geodetic Survey	4		
Panama Canal (exclusive of Army Officers)	7		
Miscellaneous	10		
	——	184	7.7%
State and Municipal Public Service.			
State Engineers	7		
City Engineers	50		
Water Supply	60		
Sewerage	16		
Streets and Highways	13		
Rivers, Harbors and Canals	36		
Wharves, Docks and Ferries	8		
Bridges	20		
Miscellaneous	91		
	——	301	12.7%
Railway Service (including Traction Lines).			
Executive Officers	30		
General Managers	20		
Chief Engineers	99		
Miscellaneous	212		
	——	361	15.2%
Manufacturing, Contracting, Etc.			
Bridge and Structural Steel Companies	85		
Light and Power Companies	48		
Contracting	156		
Manufacturing and Supplies	129		
	——	418	17.6%
Consulting Engineers.			
(Civil, Mechanical, Electrical, Sanitary, Hydraulic and Mining)	482		
	——	482	20.2%

Other Specialties.			
Architects	21		
Professors and Instructors	82		
Editors	6		
Miscellaneous	14		
		123	5.1%
Unclassified	511	511	21.5%
		2 380	100.0%

From this analysis it is not possible to classify Members on the basis of qualifications, but a fair idea of the nature of their employment may be obtained. It is to be observed that 20% of the Members are in the service of the Government, either national or local; 15% are employed on railways; 18% are engaged in manufacturing or contracting operations; 20% are consulting engineers; 5% consist of architects, professors, etc.; and 21% are unclassified. Many of the Members included in this list are also members of the National Societies of Mechanical, Electrical, and Mining Engineers, who, if restricted to one Society, might not elect to be classed among the Civil Engineers. The large number appearing as unclassified consists of those whose names appear in the list of members with their addresses given, but whose occupation is not stated. Many of these are engaged as Consulting Engineers; some were perhaps out of employment when the list was made; some have retired from active work; and others, for reasons of their own, have simply listed their addresses. It is in the nature of the Civil Engineer's occupation to have frequent changes of residence and of employment, and the list only holds good for the particular time at which it was made.

Assuming that engineers in public and railway service, and those engaged in manufacturing, etc., are salaried employees, this general class will be in the majority, the exact proportion being impossible of determination. It is also a safe assumption that, for Associate Members and Juniors, and Civil Engineers who are not members in any grade of the Society, the proportion of salaried engineers throughout the country is much greater than in the grade of Members. It is, therefore, a reasonable inference for the profession at large, that at least three-quarters of those who have employment are engaged for

salaries, and that less than one-fourth of them depend on fees for their income.

No attempt is made to classify this list with respect to rank or income. Neither the title of the Engineer, nor the class of employment, indicates the importance of his work. A chief engineer in the railway service may be in charge of 10 000 miles or of 100 miles of line, and in some instances may be vested with executive and administrative power, while in other cases this power is reserved to his employers, and he simply works under instructions. This illustration from the railway service applies to a greater or less degree throughout the list. Outside of the Government service, there is no common understanding of the duties, responsibilities, and remuneration attached to any given title for an engineer. All these appear to be fixed by the employers, and to be dependent on their personal appreciation of the man and his work. With the natural desire of employers to get as much as they can, and give in return as little as they must, there is a well-grounded belief that the average pay of the Engineer is less than it should be for the services rendered by him. Under these conditions, engineers are reticent as to their salaries and fees, and, for the purpose of studying their relation to the profession, there is no way of ascertaining what these amount to. It is an unfortunate condition that the rank and value of positions held by engineers are not more definitely fixed, and it may be taken as an indication that the engineer's status is not rightly determined. If this conclusion can be drawn from an examination of the List of Members of the Society, it will apply with more force to a consideration of the much larger number of the engineers of this country who are not included in that list.

Civil Engineers are human, and need food and clothing and shelter in common with all Mankind, and yet their subsistence is precarious. As a class, they are scattered over the country, frequently isolated from their fellow-men, and with employment of a temporary nature. They are true pioneers, preparing the way for others, without taking root and growing in the localities where their best work is done, leaving to others the cultivation of the soil which they have planted, and the reaping of profits resulting from their work. They do not generally become identified with local interests, being employed to do special work, and dismissed when that work is completed. Thus the Engineer is a means to an end for other people, who employ his services for a

remuneration, which is frequently less than their actual value, and who terminate his employment as soon as they feel they can get on without his aid. He is even sometimes classed by his employers as a necessary evil. He is considered an alien in the community, is uncertain regarding permanency of employment, and in consequence is not so capable of making plans for a domestic life as he would be if engaged in some other occupation.

The status of the profession, and the condition of its members, is better than in any former period, and yet neither is what it ought to be and will be, if engineers do their duty. The profession cannot be considered apart from its individual members. That which raises or lowers individual standards will have a corresponding effect on the profession, and any improvement must result from the work of its practitioners. It is incumbent on all engineers to engage in individual and combined efforts for the advancement of the profession, to the end that greater efficiency may be promoted, that the public may be educated into a better knowledge of what it offers, and that rewards which are more commensurate with achievement may be secured.

Let the Engineer, in examining his own condition, apply the methods which he would use if engaged to report on an engineering work, and he will search for the weak points as well as for the elements of strength. If it were a question involving the strength of materials, he would consider the circumstances of growth or the method of manufacture. His own growth may be traced back to the time when, as a youth, he decided that he wished to be a Civil Engineer, and perhaps it will be found that he was of a studious disposition, and interested in cause and effect among things, rather than among people. In his education he sought for facts; his mind was trained to view all things with precision, and to accept that which is susceptible of proof. Then, in his work as an engineer, he was segregated from others, operating as a unit, depending on individual effort, and losing much which might have been gained through combined efforts. His training and practice have taught him to regard himself as separated from his fellow-men, with the result that he becomes the tool of those whose aim is to control men and to profit by their knowledge. The end is that he is a servant where he should be a master. Herein lies the weak point in the profession—may I be pardoned for naming it professional

narrowness, while I try to point the way to convert weakness into strength. It is necessary for the Engineer to be more of a "mixer" than he has been, and to assume the initiative in many cases in which under similar conditions he has been a follower. He should be a manager, and should give orders to others who can do the work under his direction as well as he himself could do it with the situation reversed. It should not be considered unprofessional for an Engineer to be a capitalist, and, when he takes his proper place as promoter and organizer and shares in the profits of engineering enterprise, he will no longer be taunted with the saying, that "an Engineer is only good to spend other people's money." It is by acquiring individual strength that the Engineer can give strength to the profession.

It is well known that engineers of admitted proficiency often have to work under the direction of men who are unfitted by education and experience to direct engineering work. This is because the Engineer is a workman while the other party belongs to the class of "managers." The Engineer has not reached his proper rank until he can hold the position of manager, as well as that of a designer and supervisor of work. This is no plea for titles, since no title is more honorable than that of Engineer, but it is a plain statement of present conditions. A better position will be secured whenever the Engineer makes it his business to study men as well as materials, and to use men as he does machinery. The advancement must be individual, by fitting one's self for managing duties, assuming those duties, and "making good" in their performance. There is no room in the profession for trades unionism, for by its very nature it lives on competition, and its practice is a race for higher things. Let there be no mistake, however, in construing these higher things. Professional success is not wholly in building public works, or obtaining fame as a designer or director, or in the accumulation of money—all of which are worthy ends—for it includes making the name of the profession honorable, and the promotion of the welfare and happinesss of its members; and these separate objects are not inconsistent or conflicting with each other.

The same conditions and circumstances which tend to limit the advancement of the Engineer as an individual have the tendency of limiting the profession as a whole. Segregation and isolation stand in the way of combination for mutual and joint interests. While trades unions, as they are commonly understood to exist, are not to be

desired in the profession, the Engineering Societies offer the best means of united effort for its advancement.

The American Society of Civil Engineers is the representative National Society. Its reason for existence is defined in its Constitution, and, to quote exactly, its objects are "the advancement of engineering knowledge and practice and the maintenance of a high professional standard among its members." It is a mutual society, democratic and yet conservative; every right of each member is secured to him by the Constitution, and the acceptance of membership by an engineer is a practical pledge to work for the high objects for which the Society was organized. How these objects may be attained should be the subject of anxious care by all members. The profession may fairly be judged by the character of its National Society, and membership will be an honor, and a certificate of qualifications, in proportion to the reputation of the Society. University degrees are honorable, but they only certify that the possessor is prepared to enter the practice of his profession, and are not indicative of his accomplishments in it. Membership in local Engineering Societies is creditable, but usually the standards for membership in these societies are not as high as in the National Society, and it is not unusual for men of prominence in the profession to hold membership in both the local and the National Society. The local societies are not rivals of the National Society, there is need for each, and they have a common purpose which should guide them in harmonious co-operation for the good of the profession.

The American Society of Civil Engineers is the exponent of the profession in this country. As an association of leading engineers, it reflects the standing of the profession and presents to the public the means of judging and determining its status. Its diploma is a guaranty of personal worth, and its grades of membership indicate degrees of preparation for practical work. It has a total membership in all grades of more than 5 000, of which about 2 500 are Members, 1 700 Associate Members and 700 Juniors, the remainder consisting of Honorary and Corresponding Members, Associates, and Fellows. To one who has some knowledge of the engineering work accomplished in this country and of what is now in progress, a study of the Society's membership list is conclusive evidence that it represents the profession in America, and that enrollment in that list is an honor to any engineer.

The Society must grow in membership and in prestige as the profession advances, and its diploma becomes more desirable as the institutions of this country become better established. Its standards must be maintained and its representative capacity increased. It is obvious that its ranks should contain as many as possible of the engineers eligible for membership, and its advantages should be so apparent as to secure the enlistment of engineers who sympathize with its objects. To maintain its standards, it is as important to guard its gates against the admission of undesirable members as it is to open them wide for the entrance of worthy applicants. In this free country it is not always possible to protect the community by legal restriction of persons. There is nothing except sentiment to forbid an unworthy or incompetent man to call himself a Civil or Consulting Engineer, and to impose himself as such on clients who require the services of engineers but are not competent to select them. A strict regard for professional and personal qualifications will keep such men out of the Society, and, as time goes on and the Society grows in appreciation, these same clients will learn that its certificate of membership guarantees to them the qualifications they wish to secure.

Applications for membership in the Society are wholly voluntary, and the only inducements offered such applicants are the personal benefits to be derived from membership, and the opportunity to participate in its objects. Under the present system of electing members to the different grades by the Board of Direction, every member of any grade, with personal knowledge of the qualifications of an applicant, can render valuable service to the Society by contributing that knowledge to the Board. It is well to emphasize this as of great importance in properly grading such applicants as are found to be eligible for admission to membership. Common justice to all, as well as the best interests of the Society, is secured by correct grading, and the Board is guided in this work by the summary of all the information respecting an applicant, obtainable from all the members of the Society. It is, therefore, most desirable that the fullest information, with respect to qualifications, experience, and personal character, shall be furnished the Board, as it determines whether an applicant is worthy of admission and for what grade he is eligible. With the responsibility for admission to the Society resting on the thirty members of the Board, and the requirement that not less than twenty-five of them shall vote

by ballot on the names considered, the applicant's record receives the closest scrutiny, and action is not taken until all the information obtainable is canvassed. Under these conditions, it is difficult for an improper person to obtain admittance to the Society, and the opportunities for errors in grading applicants who are acceptable can be minimized by the co-operation of members who will furnish the data for classifying them.

The standing of the Society among engineers is improving. This is shown by the large increase in the number of applications, and the steadily increasing membership. The Society, by its term of existence, is of mature age, already comprising in its list of members the majority of the experienced engineers of this country, and future accessions will be from the younger members of the profession who will enter as Juniors and Associate Members, the greater part of these being in time transferred to the grade of Member. The profession is popular with young men, and the technical schools are constantly adding to their equipment to meet the demands of students for an engineering education. One Western university has this year nearly nine hundred men enrolled in the four classes of its college of engineering, and as this is only one of a number of similar institutions, it is apparent that the profession at large is growing in numbers with great rapidity. Fortunately, the growth of our new country and the extension of the field of engineering keep pace with this growth of the profession. This increase emphasizes the importance of an established status for the profession, and of the American Society of Civil Engineers, as a means of grading and certifying the qualifications of individuals for practical work.

It is gratifying to note the large number of Juniors in the Society. Young men are needed. They will not long remain young, and after they are trained as Juniors, and become Corporate Members, they will take charge of the Society, and, in turn, of the interests of the young men who follow them in the profession. Young men should be encouraged for their own good to join as Juniors, with the expectation of entering the higher grades whenever qualified, and in the meantime enjoying the benefits of the Society and sharing in its efforts to advance the standing of the profession. The only privileges denied to Juniors are the rights of voting and of holding office. The expression sometimes uttered by a young engineer that he will not join the

Society until he can enter as a Member or an Associate Member, is open to the criticism that he denies himself all the benefits of the Society with the exception already stated, and that his utterance discredits the value of membership in it. Aside from the value of professional standing conferred by such membership, there are numerous direct benefits common to all members. As all these have a bearing and influence on the subject of this address, it will not be out of place to make brief mention of some of them. The publications containing papers and discussions on a great variety of engineering subjects, written by the men who do things, are sent to all members in advance and are subsequently published in permanent form with all the discussion to which they give rise. These papers reflect the best current engineering practice, and must pass the ordeal of criticism from all members who wish to discuss them. The Library contains what is perhaps the best collection of engineering books in this country, and is available directly to resident members, and indirectly to non-resident members through searches performed by the Society's staff. The semi-monthly meetings as well as the Annual Meeting and the yearly Convention are enjoyable and profitable to such as are able to attend them. The recognition of each other among members, and the opportunities for acquaintance and friendly intercourse, are incidental benefits which in themselves should be sufficient to create a desire for membership. This should be particularly appreciated by young men who are making places for themselves in the profession. Engineers are men of high character who have a regard for the moral law and a due consideration for each other. They are an unselfish class, and it is not necessary to state that a true Engineer is willing and anxious to advance the interests of his brethren, and particularly of the young men who will take his place and do better work than he has done. One charm of the Engineer's profession lies in its recent progress. Looking backward only so far as some of the older members of the Society can remember, and observing the engineering achievements, executed, in many instances, by men without much education and with few guiding precedents, we can only wonder what the young engineers of to-day may accomplish in their lifetime with the equipment of education, and the great examples furnished by those who have stepped aside to give them the road.

The Society is under obligation to its members to advertise in all

proper ways the advantages of employing them. Our National and local government officials, private corporations, and individuals, who require the services of Engineers, should be made aware of the fact that one cannot be a member of the Society in any grade until his personal character, his professional knowledge, and his practical experience have all been investigated by a Board of thirty of the older men in the profession, who are charged with the duty of admitting into the Society only such as are proven to be worthy and competent. The Society cannot become an employment agency, nor can it recommend individuals, or discriminate in any manner among its members, but its membership list should be a reference book for the employing public. Membership in the Society at the present time is a recommendation to employers, and has a money value to those who hold it, and this value will be greatly increased in the near future, as the profession is expanded by the increasing annual additions to it.

Owing to the incoherence of the profession, it has no established code of ethics, and the influence of the Society should be exerted in this direction. The necessity of a code is not so apparent among Civil Engineers as elsewhere, for the reason that it is in the nature of the profession to abhor all that tends to fraud or quackery. Still, a code must exist, even if it is an unwritten one, and the diversity of professional employment is such that nice questions may arise between engineers, or between them and their employers or clients, which may lead them into error. The Society is perhaps not in a position to formulate and recommend such a code, and yet it can do much to establish the right relations between its members. It can, through the influence of its members, exercise a wise restraint on unprofessional tactics. Members acting in their individual capacity may create a sentiment in the profession and among employers for equitable remuneration of the engineer's services. Engineers in administrative positions may stand for fair salaries and professional consideration for those in subordinate positions. Consulting Engineers may educate their clients to a reasonable knowledge of the value of advice, and, by their conduct, may exhibit the distinction between such as are entitled to be termed Consulting Engineers and those who assume the title without the knowledge and experience to qualify them for it. One of the weak spots in the profession is the lack of a standard of capacity. It should be the case that an engineer's rating of com-

petency is established by the opinions of his fellow-engineers, whose duty it is to recognize his merits and class him accordingly. For this reason, engineers should seek to enlarge their acquaintance in the profession, and should desire the honor and responsibility of membership in the Society.

I was unable at the beginning of this address to give a definition of the Engineering Profession, and at its close I feel that I have not defined its status. This address may be subject to the criticism that it relates to the American Society of Civil Engineers, rather than to the status of the Engineer's Profession. The reply to such a criticism is to admit it to be just, and to explain that the subjects are inseparable, and that the status of the profession depends more upon the status of the Society than upon any other factor. I have not attempted any history of the profession, nor any eulogy of the great engineers who have brought it to its present condition, neither have I laid out any definite plan for the future of the profession. My desire will be accomplished if any encouragement has been given to the members of the American Society of Civil Engineers to use all its privileges and associations for the advancement of the objects which warrant its existence.

MEMOIRS OF DECEASED MEMBERS.

DANIEL DAWSON CAROTHERS, M. Am. Soc. C. E.*

DIED JANUARY 2D, 1909.

Daniel Dawson Carothers, the fifth son and seventh child of Rezin Dawson and Elizabeth Bain Carothers, was born at Cutler, Washington County, Ohio, on August 21st, 1860.

In early life, his father had been a millwright, but later he became a railroad contractor. He had a fine mechanical turn of mind, which his son inherited, and was noted for his determination and energy. His ancestors had come to America from Scotland, in Colonial days, and had settled in Huntington County, Pennsylvania. Mrs. Rezin Carothers was of English extraction, her ancestors having emigrated from England to Maryland, subsequently moving to Beaver County, Pennsylvania.

The early life of Daniel Dawson Carothers was passed on a farm, where he was required to do the "chores" and odd bits of work which fall to the lot of a country boy. This early experience tended to develop both mind and body, and the boy showed a strong liking for work with tools and for everything which pertained to machinery. His mother exerted a strong influence over his early life and intellectual development, giving him his primary schooling, as the neighboring country schools, in those days, were poor and the term of study very short. The last year or two of Mr. Carothers' school life was spent at Bartlett Academy; later, he went to the National Normal University at Lebanon, Ohio, where he took a special course in engineering, although he did not enter for a degree. During the last three years of Mr. Carothers' college life, he taught school during the winter months. Finally, in 1882, he began his labors in the field which he had chosen for his life work. At that time his father was connected with the Wheeling and Lake Erie Railroad, and the young civil engineer was given employment as a Rodman under his father, who early impressed upon him, as the primary necessity for success in business, the spirit which would "always obey orders."

As Rodman and Assistant Engineer, Mr. Carothers was with the Wheeling and Lake Erie Railroad during 1882. The next year he entered the service of the Columbus and Cincinnati Midland Railroad (now a part of the Baltimore and Ohio System), serving as Assistant Engineer, Chief Engineer, and Train Master. He remained with this Company for seven years, or until 1890, when he transferred the field of his activity to the Baltimore and Ohio Railroad, with which road, or its subsidiary lines, he remained until his death.

When Mr. Carothers entered the service of the Baltimore and Ohio

* Memoir prepared by Paul Didier, M. Am. Soc. C. E.

in 1890, it was as Engineer of Maintenance of Way of the Baltimore and Ohio Southwestern, which position he held until 1901. He then became Superintendent of the Chicago Division of the Baltimore and Ohio Railroad, with headquarters at Chicago; two years later, in 1903, he was made General Superintendent of the Baltimore and Ohio Southwestern, with headquarters at Cincinnati. In 1904 he was chosen Chief Engineer of the Baltimore and Ohio Railroad, with headquarters at Baltimore, which position he held at the time of his death.

Mr. Carothers was married on September 20th, 1888, to Miss Carrie Leland of Lewiston, Maine. They had one child, a son, who lived only a short time. Mr. and Mrs. Carothers resided in Baltimore for the past five years, and made many friends. Mr. Carothers was a Member of the Maryland, Merchants, Baltimore Yacht, Baltimore Country, and Engineers' Clubs of Baltimore; the St. Louis Railway Club; the Western Railway Club of Chicago; the American Railway Association; the National Geographic Society; the American Railway Engineering and Maintenance-of-Way Association, of which he was a Director and Chairman of the Rail Committee; a Member of the Committee on Conservation of National Resources, having attended the two conferences of the Governors of the States with the President of the United States, at Washington; the Ohio Society of New York; and the Madisonville Lodge of Masons.

Entering the service of the Baltimore and Ohio Railroad on the eve of a new era in railroading in America, while the many companies were beginning such marvelous strides in the way of development, Mr. Carothers played an important part in the upbuilding of one of the greatest railroad systems in the country. During the years he filled the many important positions to which he was chosen prior to 1904, he was instrumental in directing much of the energy then being devoted to railroad improvement.

Mr. Carothers was a man of pleasing personality, and typified, not only a success as an engineer, but a success as a man. As an engineer and railway official, he had initiative power, and his education and large experience, backed up by one of his most dominant characteristics—common sense—gave great strength to his views among other men of his Profession. As a man, his sterling qualities and manliness drew everyone to him. The men who worked in close touch with him were those who most appreciated and respected his opinions. Notwithstanding the position in the railway world which he had made for himself, those who knew him felt that this was but the beginning of his true usefulness, and all experienced a deep sense of personal loss at his death.

"The world was better because he lived. A noble spirit has gone to rest."

Mr. Carothers was elected a Member of the American Society of Civil Engineers on April 4th, 1904.

JOSEPH MARSHALL GRAHAM, M. Am. Soc. C. E.*

DIED FEBRUARY 3D, 1909.

Joseph Marshall Graham was born at Crawfordsville, Indiana, in 1850. He received his education at the Kentucky State University, at Lexington. He began his railroad career, in 1873, as Assistant Engineer on the Grayville and Mattoon Railroad, now a part of the Illinois Central. From 1874 to 1875 he was Assistant Engineer on the Bedford, Springville, Owensburg and Bloomfield Railroad; and, from 1875 to 1876, he served as Chief Engineer of the same road. After that time he held the following positions:

From 1876 to 1881, Chief Engineer of the Danville, Olney and Ohio River Railroad; from October, 1881, to April, 1882, Chief Engineer of the Chicago, Texas and Mexican Central Railway; from April, 1882, to April, 1883, General Superintendent of the Danville, Olney and Ohio River Railroad; from April, 1883, to October, 1888, Superintendent of the Dakota Division, Northern Pacific Railroad; from October, 1888, to October, 1890, General Manager of the Northern Pacific and Manitoba Railway of the Northern Pacific System; from October 1st, 1890, to July, 1891, Assistant General Superintendent of the Northern Pacific Lines East of Livingston, Montana; from September, 1891, to January 1st, 1898, Superintendent of the Ohio and Midland Divisions, Baltimore and Ohio Railroad, at Newark, Ohio; from January 1st, 1898, to July, 1899, General Superintendent of the Trans-Ohio Division of the same road; from July 1st, 1899, to February, 1904, Chief Engineer of the Baltimore and Ohio Railroad at Baltimore, Maryland; from February, 1904, to 1908, Vice-President of the Erie Railroad; and, in 1908, he was made Vice-President of the New York, Susquehanna and Western Railroad, which position he held at the time of his death.

Mr. Graham was one of the pioneers in advocating and carrying out important grade-reduction work, to lessen train-mile cost; and while Superintendent of the Baltimore and Ohio Railroad, in 1893, he commenced the modification of the grades on the Lines West of the Ohio River. During the time he was Chief Engineer of that road, surveys were made, and a low-grade line was located from Baltimore to Chicago, a considerable portion of this line being constructed under his direction, viz., from Baltimore to Brunswick, Maryland; various grade-reduction improvements were made between Harpers Ferry and Cumberland; a freight line was constructed around Cumberland, as well as a line from Youngstown to Akron; grade reductions were made on the Cleveland, Lorain and Wheeling Railroad, together

*Memoir prepared by Francis Lee Stuart, M. Am. Soc. C. E.

with various grade reductions in connection with double-tracking the Lines West of the Ohio River.

When it was determined by the Directors of the Erie Railroad to relocate certain portions of its lines, in order to make it a low-grade line between Chicago and New York, Mr. Graham was called from the Baltimore and Ohio Railroad to take charge of the work as Vice-President of the Erie Railroad; and it was under his direction that plans and surveys were made for a line from New York to Cleveland with a ruling gradient of 0.2% east and 0.3% west, and the Erie and Jersey Railroad and the Genesee River Railroad, which are parts of this low-grade line, were constructed.

During 1908, Mr. Graham had relinquished some of the executive duties of his office to engage as Consulting Engineer in several large enterprises in different parts of the United States.

Mr. Graham was a man of large ideas, holding broad views of the railroad questions of his time, and his habits of mind, mature judgment, and sound conclusions on all practical topics of railway economics, made him an invaluable addition to any organization.

In 1906, the Kentucky State University conferred on him the degree of Doctor of Engineering.

In 1880 Mr. Graham married Miss Evelyn Norton, daughter of the Reverend Albert Norton, of Cleveland, Ohio, who survives him.

Mr. Graham was elected a Member of the American Society of Civil Engineers on April 4th, 1900.

RUTGER BLEECKER GREEN, M. Am. Soc. C. E.*

DIED DECEMBER 8TH, 1908.

Rutger Bleecker Green was born in Syracuse, New York, on October 8th, 1868, and was the second son of Andrew Heatley Green, a prominent attorney of that city, and Mary Miller Green. He prepared for college in the public schools of Syracuse, New York, and Morristown, New Jersey, and entered Cornell University in 1890. He was graduated with the Class of 1895, having lost one year because of sickness. As an expression of their appreciation of his ability and of their regard for him, his classmates, during his Senior year, bestowed upon him the highest honor within their power by electing him Chief Engineer of the survey made by the Senior and Junior classes at the northern end of Owasco Lake, New York.

Previous to entering college Mr. Green had had considerable practical experience, having been engaged as Chainman on the New York State Canals; Chainman and Instrumentman on the Richmond and Danville Railroad; Chainman on the Adirondack and St. Lawrence Railroad; and Assistant Engineer on the construction of the Syracuse Water-Works' pipe line from Skaneateles Lake, being in charge of a cross-section and construction survey party, on Sections 1 and 3, in 1893.

After graduation, Mr. Green was an Assistant on the editorial staff of *The Engineering Record* for nearly two years. He left *The Record* to accept the position of Leveler on the New York State Canals. In November, 1898, he accepted a position as Civil Engineer with the Detroit Works of the Solvay Process Company, in which position he remained until his death. He had charge of the land surveys of the 400-acre plant on the Detroit River; designed and constructed a yard system of 8 miles of tracks, with 75 turn-outs and an 8-stall locomotive house, 1 mile of concrete sewers, 2 miles of gas and water pipe for manufacturing and fire protection, including a yard system of 40 hydrants, and automatic sprinkler systems. He also supervised the construction of the foundations and superstructure of a 300-ft. railroad draw-bridge and coal-car tipple, and the enlargement of the foundations of a 260-ft. chimney, also the foundations of various office and factory buildings, including lime-kilns, dynamo-house, ammonia tanks, concrete bulk-soda storehouse and office building.

Personally, Mr. Green's disposition was particularly loving and sympathetic, and all with whom he came in contact were pleased to call him friend.

Special mention should be made of his interest in religious and

* Memoir prepared by M. S. MacDiarmid, Assoc. M. Am. Soc. C. E.

philanthropic affairs, as at the time of his death he was Treasurer of St. Mark's Episcopal Church at Delray, and a Trustee of D'Arcambal Home.

Too close application to his work, and the intense interest which he took in everything in which he engaged, resulted in a nervous breakdown. In June, 1907, Mr. Green took a trip to Europe for his health, but he was not permanently benefited.

A recurrence of the old trouble during the summer and fall of 1908 caused such a state of mental depression that, with the words, "I am worked out," he sought rest in death, on December 8th, 1908.

Mr. Green was elected a Junior of the American Society of Civil Engineers on May 5th, 1896; an Associate Member on October 5th, 1898; and a Member on September 6th, 1904. He was elected a Member of the Detroit Engineering Society on October 26th, 1900. He contributed valuable discussions to each of these Societies.

CHARLES MacRITCHIE, M. Am. Soc. C. E.*

DIED JANUARY 27TH, 1909.

Charles MacRitchie was born in Inverness, Scotland, in 1844. From 1860 to 1865, he served as an apprentice with G. E. Mackay, Land Surveyor and Civil Engineer, of Inverness, Scotland.

Mr. MacRitchie began his professional work in 1866, in the office of Edward Blythe, of Edinburgh, Scotland, being employed on the construction of the Dingwall and Skye Railway. Part of the time he acted as Resident Engineer on the western half of the road.

In 1869, Mr. MacRitchie came to the United States and, after a short stay in New York, went to Chicago, where he was employed in the private office of the late E. S. Chesbrough, M. Am. Soc. C. E. (who, at that time, was City Engineer), in making plans for a railway tunnel under the Detroit River, at Detroit, Michigan.

Under the direction of and in association with Mr. Chesbrough and the late Moses Lane, M. Am. Soc. C. E., Mr. MacRitchie made surveys and plans for the water supply of Pittsburg, Pennsylvania, and Long Island City, New York. He was also Principal Assistant Engineer on the construction of the water-works for Milwaukee, Wisconsin, and afterward served as Secretary of the Board of Trustees.

In 1875, Mr. MacRitchie entered into partnership with John Nichol, M. Am. Soc. C. E., under the firm name of MacRitchie and Nichol, Engineers and Contractors, which partnership continued until 1906. This firm prepared plans and contracts and carried out work, either for a complete water supply, or a part thereof, in many cities in the United States, which included some interesting submerged-pipe work in Galveston, Texas, Boston, Massachusetts, and St. Paul and Minneapolis, Minnesota, and also some railway-construction work.

From 1906 until his death, Mr. MacRitchie was in partnership with Mr. Benezette Williams, engaged in railway and other contracting work.

By his genial, kindly and generous disposition and straightforward honesty of purpose, Mr. MacRitchie made many friends wherever he went.

Mr. MacRitchie was elected an Associate of the American Society of Civil Engineers on October 2d, 1872, and a Member on April 5th, 1876.

*Memoir prepared by John Nichol, M. Am. Soc. C. E.

CHARLES TARBELL DUDLEY, Assoc. M. Am. Soc. C. E.*

DIED SEPTEMBER 30TH, 1908.

Charles Tarbell Dudley was born in Richmond, Indiana, on April 6th, 1878. He received his technical training at Sheffield Scientific School of Yale University and at the Colorado State School of Mines. He was graduated from the former with the degree of Ph. B. in 1900, and from the latter with the degree of E. M. in 1902.

While a deep student and an investigator along original lines, his memory is particularly lasting at these two schools because of his tireless efforts in the upbuilding of clean, wholesome, college athletics. Though small, Mr. Dudley was an athlete of the wiry, determined type, and Harvard and Princeton still remember him as a most dangerous half-back, centerfielder, and batsman. Determination and a high moral standard were his chief characteristics, and these, coupled with a cheerful, lovable disposition, endeared him to all his associates.

Before taking up his post-graduate work at the Colorado State School of Mines, Mr. Dudley secured employment as Assistant Chemist at the Midvale Steel Works. In six months his ability was recognized to such an extent that he was put in charge of the Department of Metallography and Experimental Chemistry, and in another six months he had invented a new process for the treatment of large, nickel-steel forgings, which nearly eliminated the imperfections so frequent before that time.

After his post-graduate course, Mr. Dudley went to California and acted as Superintendent of various mining properties until September, 1903, when he accepted employment with the Engineering Department of the Bay Cities Water Company, which corporation was at that time designing a new water supply for the City of San Francisco.

In 1905 Mr. Dudley resided in the Santa Cruz Mountains, California, and designed the trestles and bridges for the Santa Cruz Portland Cement Company's railroad. The great California earthquake of 1906 interrupted this work, and, seeing the opportunity for designing and structural engineers in the rebuilding of San Francisco, Mr. Dudley moved to that city. He was engaged in the design of some of the largest of San Francisco's new buildings when he was seized with an attack of typhoid fever, and for six weeks he fought for his life with his characteristic determination. Before he had regained his strength he moved to Allston, Massachusetts, and began again the practice of his profession. His strong constitution, in its weakened condition, could not stand this added strain, and a general breakdown resulted, against which his determination and grit were unavailing.

* Memoir prepared by H. L. Haehl and C. E. Gilman, Assoc. Members, Am. Soc. C. E.

Mr. Dudley died on September 30th, 1908. His wife, Sarah Emery Dudley, whom he married in Boston, in 1905, and two children, Sarah and Wade, survive him.

To those who knew him his death was a keen blow; to his friends, it was a great loss—the loss of that great possession, a wholesome, manly man and a true friend.

Mr. Dudley was elected a Junior of the American Society of Civil Engineers on September 6th, 1904, and was transferred to the grade of Associate Member on October 3d, 1906.

CLINTON GLENCAIRN WELLS, Assoc. M. Am. Soc. C. E.*

DIED AUGUST 16TH, 1908.

Clinton Glencairn Wells was born in Galveston, Texas, on December 13th, 1874. He attended school in Galveston, and in Lawrenceville, New Jersey. He was graduated from Princeton University, in Civil Engineering, in 1898. His first employment in his chosen profession was with the Jersey City Water Supply Company of Boonton, New Jersey, in 1899, in the capacity of Assistant to the Engineer in charge of a party making preliminary surveys and location of the works to carry out a $7 695 000 contract with Jersey City.

On May 1st, 1900, Mr. Wells accepted a position with the Electrical Commission of Baltimore City, in the capacity of Engineer in Charge of Distribution, on an underground conduit system for the reception of wires of all classes. In October, 1901, he left the Electrical Commission to accept a position with the Maryland and Pennsylvania Railway Company, as Assistant Engineer in Charge of Reconstruction Work in Western Maryland, straightening the line and laying out new curves.

On June 10th, 1902, Mr. Wells was elected City Engineer of Galveston, Texas, in which capacity he served faithfully until May, 1907, when, by reason of ill health, he was forced to resign. At the time Mr. Wells was elected the city was just beginning to recover from the great calamity of 1900, and his five years of service might be termed the period of its rehabilitation; most of the improvements, both public and private, were due to his skill and wisdom, and were made under his immediate supervision.

In December, 1904, Mr. Wells was married to Miss Josephine Kenison, of Galveston, Texas, who with their only child, Clinton G. Wells, Jr., and one sister, Miss Hetty L. Wells, residing in Baltimore, Maryland, survives him.

One of Mr. Wells' friends and associates, Mr. W. A. Nicholson, in a recent letter, feelingly expresses sentiments held by all who really knew him:

"No words can be written that will fully express the purity of purpose that ever actuated this noble hearted boy. It can be truly said, that the light which filled his manly breast would permit him to 'sit in the center of night and enjoy bright day' and why Fate should deal so unkindly with him, and why he should die so young in the very spring-time of his manhood, is to me a mystery."

Mr. Wells was elected a Junior of the American Society of Civil Engineers on March 5th, 1901, and an Associate Member on March 1st, 1905.

* Memoir prepared by John B. Hawley, M. Am. Soc. C. E.

OLIN McCLINTOCK BOYLE, Jr., Jun. Am. Soc. C. E.*

DIED AUGUST 19TH, 1908.

Olin McClintock Boyle, Jr., was born near San José, California, on July 5th, 1886. He was graduated from the grammar grades of the Willow Glen School, and entered the Santa Clara High School in September, 1898. Six months later his family removed to San Francisco, where he entered the Lowell High School. During the summer vacation of 1901 he was induced by the city editor of the *San Francisco Examiner* to become a writer on that paper. His short newspaper career was unusually promising. He rapidly rose to something more than a mere reporter. Later, he accepted the sporting editorship of the *San Francisco Evening Post*, and held it until October, 1902, when he re-entered the Lowell High School, from which he was graduated in December of that year. He was admitted to the University of California in January, 1903, and was graduated from its College of Civil Engineering in December, 1906, having completed most satisfactorily the usual four-year course.

Immediately after his graduation Mr. Boyle went to the Greenwater Copper District of Inyo County, California, as Assistant to Mr. Alfred J. Cleary, remaining until the camp was closed. Returning to San Francisco, in May, 1907, he received an appointment as Instructor in the Santa Cruz Summer School of Surveying of the University of California. At the close of this session, he was employed for a short time by the Modesto Irrigation District Company, but left their employ to accept a position as Engineer with the Associated Pipe Line Company. Early in 1908 he became connected with the Union Construction Company, with headquarters in Calaveras County, California, and was in the employ of this company when he met his untimely death on August 19th, 1908.

In his short life Mr. Boyle gave promise of an unusually active and successful career. He was a man of great physical strength, and was a most industrious worker. He had a charming personality. He was constantly on the alert to be of service to others and to make others happy.

Less than two years elapsed between his graduation from his University and his death, but in that short time he gave numerous evidences of his love for his Alma Mater, and showed by his acts that he fully realized his indebtedness to the institution which trained him.

His early experiences in newspaper work had given him a taste for reading, and he was unusually well informed. In the year preceding his death, he contributed a number of short articles to the *California*

*Memoir prepared by Charles Derleth, Jr., M. Am. Soc. C. E.

Journal of Technology, wherein he showed promise as an engineering author.

It is fitting that the *Transactions* of the Society, which represents most broadly the profession he revered, should contain a statement of his life and work so that those who were associated with him may be reminded of his substantial character and loving personality.

Mr. Boyle was elected a Junior of the American Society of Civil Engineers on March 5th, 1907.

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